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INSTRUMENTATION FOR VERIFICATION OF BOMB DAMAGE REPAIR COMPUTER CODE

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Field data on repaired bomb craters must be collected to verify responses of the crater predicted by the bomb damage repair (BDR) computer code. Instrumentation to measure the repaired bomb crater responses due to static and dynamic loads was reviewed. Equipment was recommended and provided to AFESC/RDCR that would allow comparison of predicted and measured responses for BDR code verification. An instrumentation user's manual and a quick-look data report on an instrumentation test performed at North Field, South Carolina, are presented in the appendixes.

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PREFACE

This report was prepared by the New Mexico Engineering Research Institute, University of New Mexico, at the Eric H. Wang Civil Engineering Research Facility, Kirtland Air Force Base, New Mexico under Contract F29601-76-C-0015 and Contract F29601-81-C-0013, Job Order 21042B47 for Headquarters, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida.

This report summarizes work done between March 10, 1980 and September 30, 1981. Mr. Phillip Nash was the Task Officer.

The author wishes to thank Mr. Daniel Kutz, Research Engineer, and Mr. Jack Babcock, Technician, of the New Mexico Engineering Research Institute (NMERI) Instrumentation Division for writing the instrumentation user's manual presented in Appendix A of this report.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

BACKGROUND

To retain an operational capability after an attack, an airbase must be able to repair the damage to its airfield. A section of the airfield with the least amount of damage and shortest repair time, called a minimum operating strip (MOS), must be selected. Explosive ordnance disposal (EOD) teams must clear the MOS of any unexploded ordnances so that bomb damage repair (BDR) teams can repair the MOS.

The repair of bomb craters involves backfilling the crater and capping the repair with a material sufficiently strong and smooth to allow safe aircraft operation. The repair must be strong enough to support military aircraft without danger of excessive deflection under load, and it must be highly durable or traffickable to allow a large number of passes or operations of aircraft without excessive deterioration such as rutting. In the past, these strength parameters have been evaluated by expensive and time-consuming field tests for various types of materials and repair techniques before their recommendation and adoption as standard military procedures. However, with the aid of modern computers it is possible to perform a structural evaluation of a repaired bomb crater and thus to reduce or eliminate the field testing and evaluation effort.

A bomb damage repair computer code (Reference 1) has been developed by the New Mexico Engineering Research Institute (NMERI) of the University of New Mexico. It is capable of calculating the stresses, strains, and deflections of a repaired bomb crater due to the static load of single- or multiple-wheel aircraft. The BDR code is a version of the AFPAV and PREDICT computer codes (References 2 and 3), modified to perform structural evaluations of repaired bomb craters. As with any calculational technique used to predict performance, the BDR code must be validated by comparing calculated crater responses with known or measured crater responses.

SCOPE

The scope of this research effort was to develop an instrumentation plan to gather field test data for comparison with analytical predictions from the BDR computer code. The BDR code was reviewed and parameters that could be measured in the field were identified. A literature survey was performed of available equipment that could measure these parameters. Following the approval of the Air Force Engineering and Services Center (AFESC), the equipment was procured and transferred to AFESC personnel who received a demonstration in the use of the equipment and data collection techniques. The task originally required NMERI supervision of AFESC personnel who would perform the North Field Demonstration Test at North Field, South Carolina, during August 1980. However, changes in AFESC personnel resulted in NMERI personnel performing the necessary instrumentation effort during the field test. Appendix A contains an instrumentation user's manual. Data collected at North Field were analyzed by NMERI and documented in a data report included in Appendix B.

OBJECTIVE

The objective of the task was to recommend and procure the equipment necessary to instrument repaired bomb craters during field tests or simulated repaired craters at the AFESC Test and Evaluation Site, Tyndall Air Force Base, Florida. The equipment would measure selected crater responses for comparison with calculated crater responses from the BDR code.

SECTION II

INSTRUMENTATION REVIEW AND RECOMMENDATIONS

To familiarize the reader with the BDR code, a brief description follows. More detailed information can be obtained from Reference 1.

The BDR code is a nonlinear finite-element analysis program. The input consists of aircraft characteristics, true crater profile, layer thicknesses, and material properties. The code develops a model of the repaired crater consisting of rectangular sections or elements, each element having a certain strength or stiffness defined according to the layer thickness and material property information. The static wheel load of an aircraft is applied to the elements corresponding to the contact area of the tire. The wheel load is mathematically distributed to the elements comprising the crater model according to each element's stiffness. Finally, the deflection, stress, and strain produced by the aircraft wheel load are tabulated or plotted for various locations of the crater model.

The selected output of the code is designed around a rational pavement analysis procedure (see Reference 4 for a review of conventional pavement design and evaluation procedures). For conventional pavements the critical evaluation parameters are the subgrade compressive strain, surface material maximum tensile strain, and tensile stress. The subgrade compressive strain must not be excessive or the pavement may fail under load due to excessive deflection. The maximum tensile strain is an evaluation and design criterion for flexible pavements such as asphaltic concrete. Flexible pavements are designed to absorb the applied stress within different material layers. Laboratory experiments have verified that asphaltic concrete beam specimens fail by excessive tensile strain at the extreme edge of the specimen under load. The tensile stress criterion is utilized with rigid pavements, such as portland cement concrete (PCC), that are designed to distribute the applied stress to different material layers. Failure algorithms for PCC pavements indicate that the life of the pavement is inversely proportional to the maximum tensile stress produced in the pavement. Thus, for the PREDICT pavement analysis code the output consists of the subgrade compressive strain and maximum tensile stress or strain. These values are compared with fatigue algorithms that predict the number of allowable aircraft operations.

These procedures have been accepted for evaluating pavement performance, because paving materials typically are of high quality and are placed and compacted to design specifications. However, BDR repair techniques and materials may not be of the same high quality as those for pavements. The craters may have to be repaired under adverse conditions and with a lack of resources, materials, equipment, and manpower. Thus, the performance of the repaired crater is less consistent due to differences in materials, procedures, and repair conditions.

In the repair process, the crater ejecta are cleared from the area after a portion is pushed back into the crater. This material is very nonhomogeneous and may contain sections of the fractured pavement and varying amounts of the base course and subgrade materials. The pushback material receives very little, if any, compaction, causing greater variations in material properties which may effect crater performance.

The surface of the repair may be a material similar to the original pavement or a select fill material capable of supporting the anticipated aircraft operations. Present procedures recommend a well-graded, crushed limestone material containing both large and small particles to optimize the density and strength characteristics of the material. Other materials considered by the Air Force include epoxy resins and rapid setting cements that provide in a very short time a sufficiently strong crater repair for aircraft operations.

If an approach to bomb damage repair similar to rational pavement evaluation and design is utilized, then the same parameters (subgrade compressive strain, maximum tensile strain, and tensile stress) may be used to evaluate repaired bomb crater performance. However, consideration must be given to those aspects of the evaluation peculiar to bomb damage repair. Due to the nonhomogeneity of the pushback material, any measurements made in this area are likely to indicate erratic behavior and large variations in the collected data. The pushback material will compact and consolidate with time; traffic or environmental changes will accelerate this process. Stress concentrations will develop in the area containing sections of pavements or other foreign debris in the pushback.

LITERATURE REVIEW

Because of the unknown factors associated with bomb damage repair and the wide variety of materials that may be tested, no single measurement device could be recommended for use in the instrumentation of repaired craters. It was requested that, in addition to recording static measurements, the instrumentation be capable of recording dynamic measurements and synchronizing with instrumented aircraft for comparison of responses. A literature survey was performed to investigate the types of instruments presently utilized to measure stress, strain, and deflection. After measurement devices were tentatively selected an instrumentation system was designed to allow recording data due to static and dynamic loads.

PRESSURE GAGES

A literature review was performed to evaluate devices that have been used to measure pressures in soils and pavement systems. A brief discussion of the different types of gages reviewed is presented here.

The first gage type is a membrane- or diaphragm-type gage consisting of one or two thin deflecting surfaces that are in contact with the soil. When pressure is applied to the gage surface, the resulting deflection is measured by one of three different methods: (1) strain gage, (2) vibrating wire, or (3) pressure transducer. In method 1 one or two strain gages are placed on the interior surface of the deflecting gage membrane, as shown in Figure 1. As the membrane deflects, the length of the strain gage is increased causing a corresponding change in resistance and voltage. Calibrations are performed in the laboratory to correlate the voltage ouput with the applied stress. Method 2 involves a wire stretched between a fixed point of the gage and the

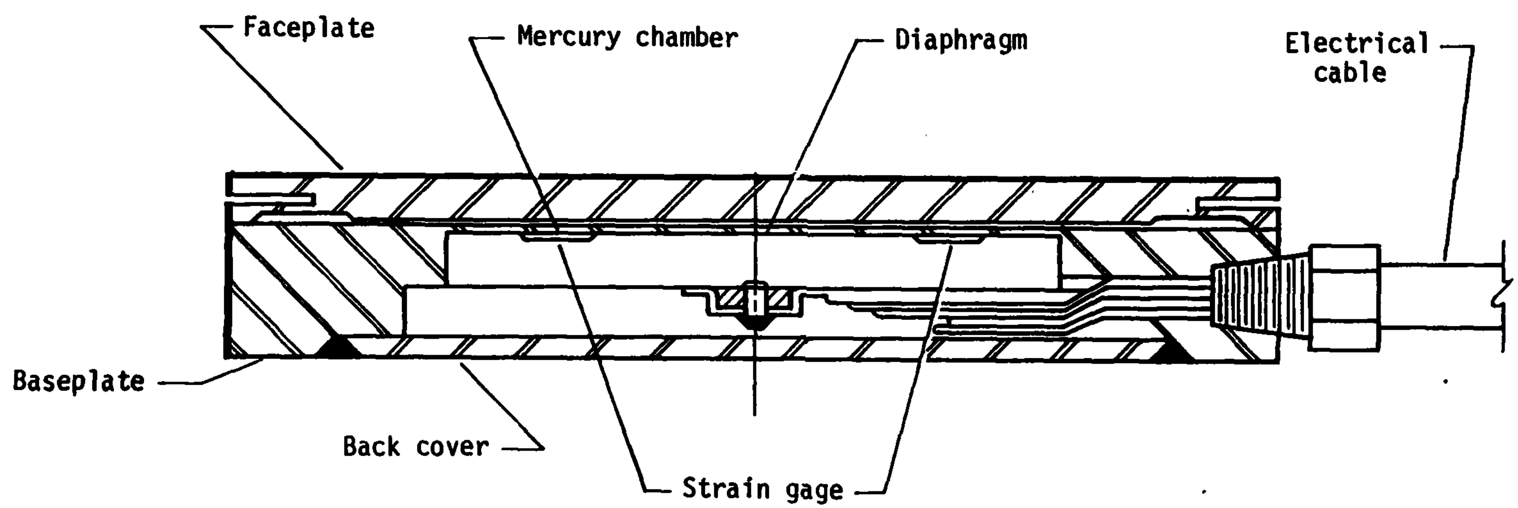


Figure 1. Strain-Gaged, Membrane-Type Pressure Gage (Ref. 14).

inside face of the deflecting membrane, as shown in Figure 2. The length of the wire changes as stress is applied and the membrane deflects. The change in length of the wire is determined by vibrating the wire and recording the frequency of oscillation, which calibration data can correlate to the applied stress. The third method, presented in Figure 3, utilizes a pressure transducer to indicate changes in the internal pressure of a gage that is filled with an incompressible fluid. As stress is applied and the membrane deflects, the internal volume of the gage is decreased, causing an increase in the fluid pressure.

Another type of gage developed at NMERI and shown in Figure 4 is the column- or spool-type gage that is similar to a load cell. The column gage consists of a strain-gaged aluminum cylinder whose flat surface is exposed to the soil. Pressure on this face causes the column to deflect and the measurement is made using the output of the strain gage.

Because of the nonhomogeneity of the crater backfill materials, a large surface area gage was deemed necessary to attempt to average any stress concentrations in this application. A large surface area gage would also contribute to less data scatter or variability caused by other factors such as gage placement effects. These criteria eliminated the column- or spool-type gage.

Another consideration of the soil stress gage was that the gage must be as thin as possible to minimize arching of the soil around it. This arching would cause the measured response to be greater than the actual response. Ideally the gage should match the stiffness properties of the soil so that the placement of the gage does not disturb or alter the stress field. Figure 5 shows the effects of different gage thickness-diameter ratios and the modular ratio of the soil and gage on the response of the gage. For a particular thickness-diameter ratio, the gage will underregister if the gage is less stiff than the soil and will overregister if the gage is stiffer than the soil. For a particular modular ratio less than unity, the gage underregisters in direct proportion to the thickness-diameter ratio. If the gage

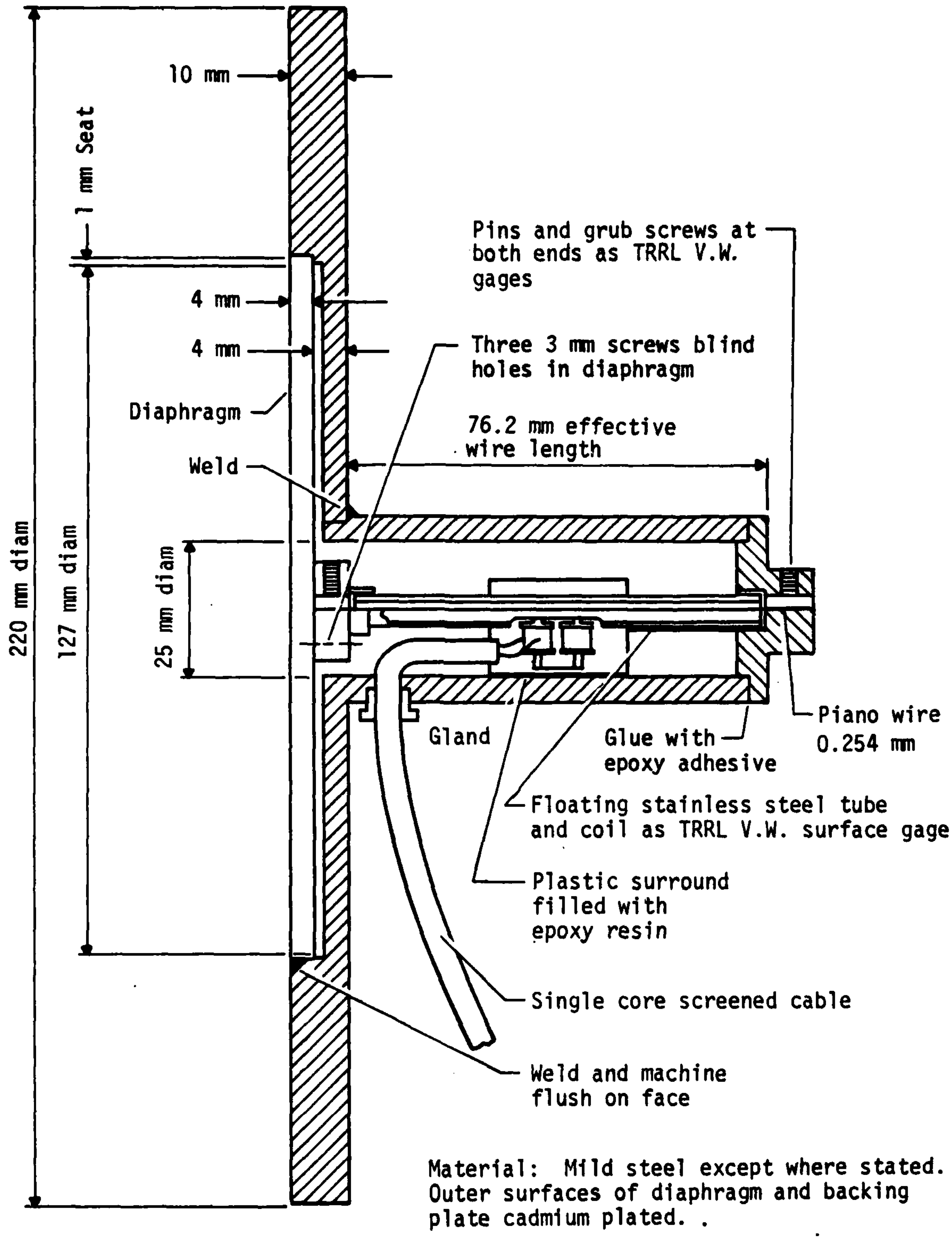


Figure 2. Vibrating Wire, Membrane-Type Pressure Gage (Ref. 8).

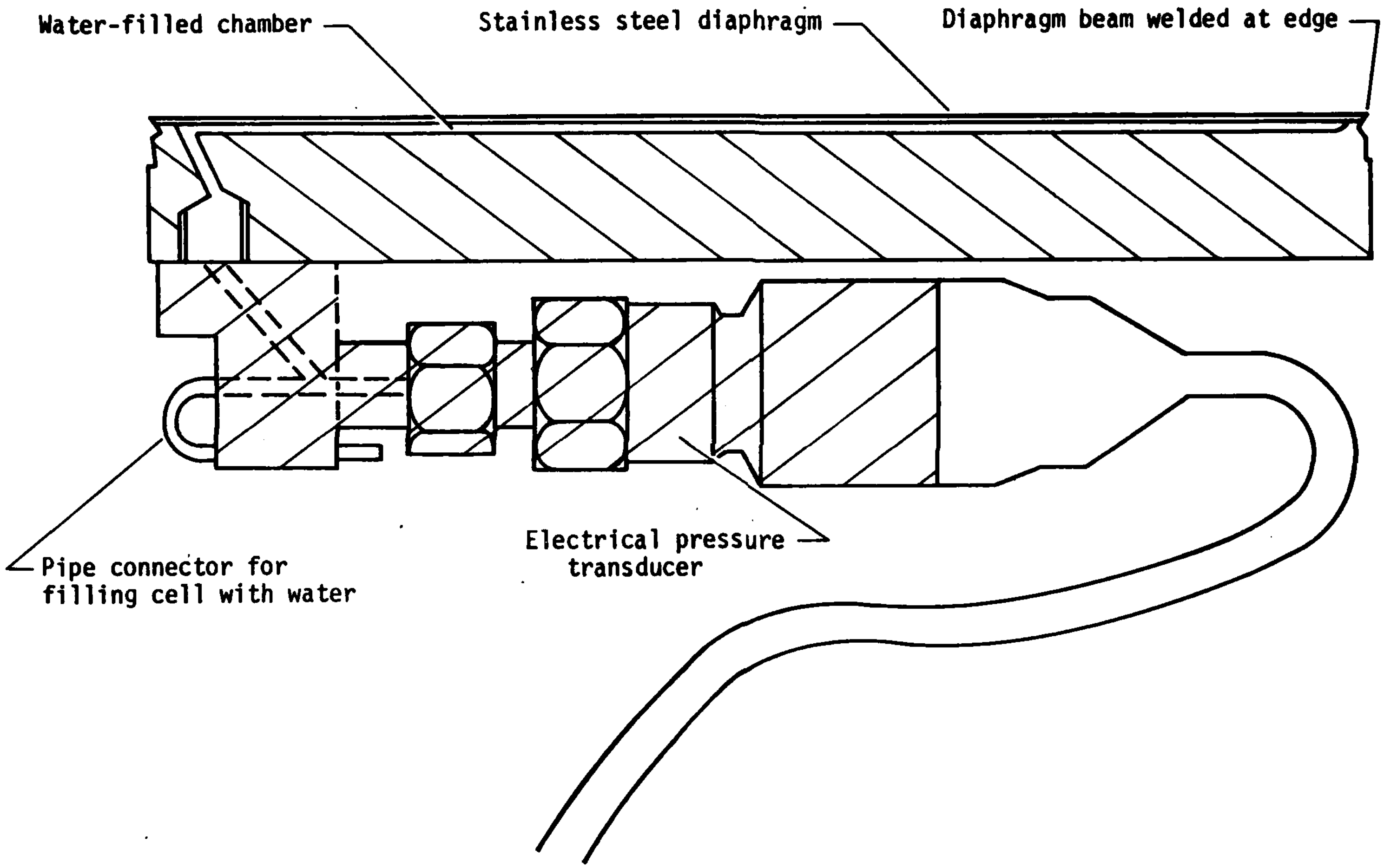
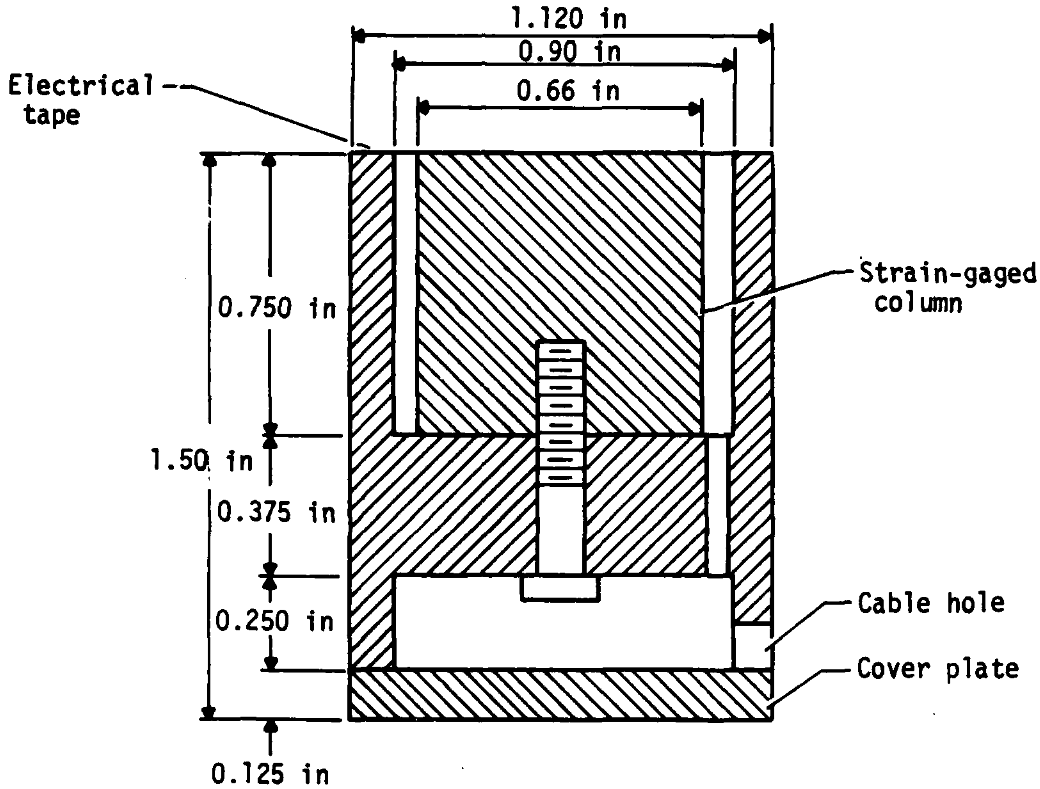
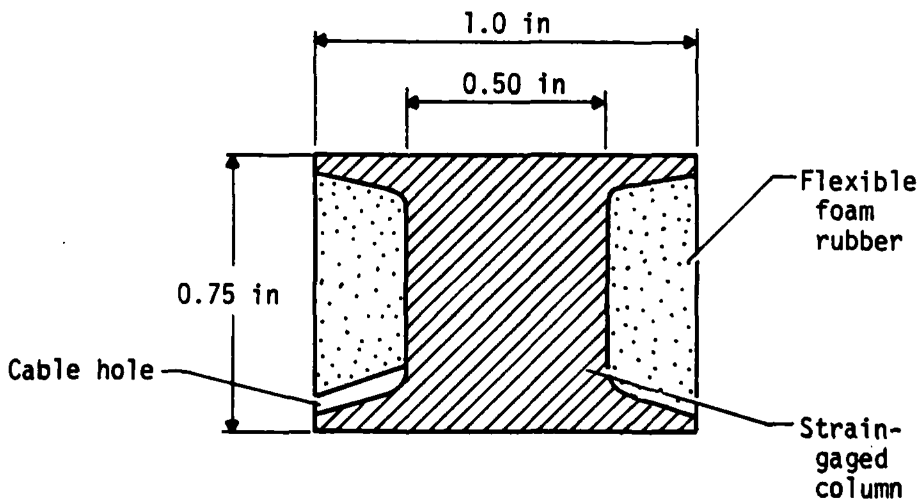


Figure 3. Pressure Transducer Or Hydraulic Membrane-Type Pressure Gage (Ref. 9).



a. UNM column stress gage (after Lynch, 1966).



b. UNM spool stress gage (after Abbott, et. al., 1967).

Figure 4. Column- And Spool-Type Stress Gages (Ref. 5).

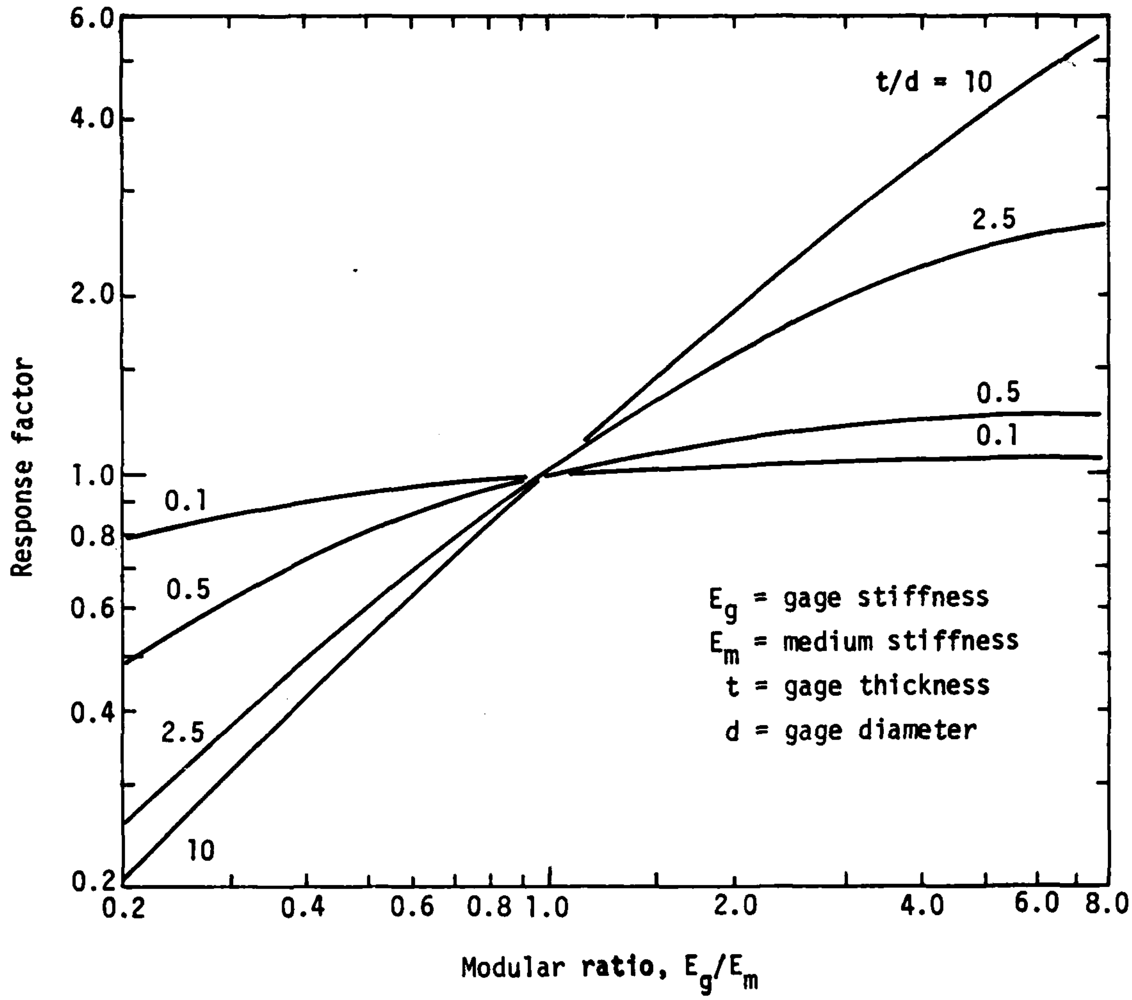


Figure 5. Soil Stress Gage Response (Ref. 5).

is stiffer than the soil, overregistration occurs in direct proportion to the thickness-diameter ratio. Therefore, the ideal gage should match the stiffness of the soil exactly for agreement with the measured and actual field responses. However, this would require that each gage be individually designed for the type of soil in which it is to be located. This is an impractical approach. Referring to Figure 5, gage under- and overregistration can be minimized independently of modular ratio if the gage thickness-diameter ratio is as small as possible.

Most of the pressure gages utilized in the field and documented in the literature were for measuring soil-structure boundary pressures. However, some testing did include soil pressure measurements and typically used the membrane-type gage. References 5 through 13 provide an adequate background for assessing the operation of the gages and present some typical applications.

The conclusions reached after reviewing these references are: (1) membrane-type gages have been successful in measuring both static and dynamic soil pressures (Reference 10); (2) the pressure gage should be slightly stiffer than the medium in which the gage is placed; (3) the gage should have a large diameter-thickness ratio to minimize arching effects; (4) gage diameters ranged from approximately 2 to 15 inches, and typically were from 6 to 10 inches.

STRAIN GAGES

The literature review yielded very few articles on soil strain gages (References 14 through 17). Reference 14 is a state-of-the-art report and describes two types of soil strain measurement systems.

The first consists of two plates located at some distance from each other and connected by a rod that is free to move, as shown in Figure 6. Mounted on the end of the rod is the core of a displacement transducer that mates with the inductive coil mounted on the other plate. Movement is indicated by the position of the core within the coil similar to a Linear

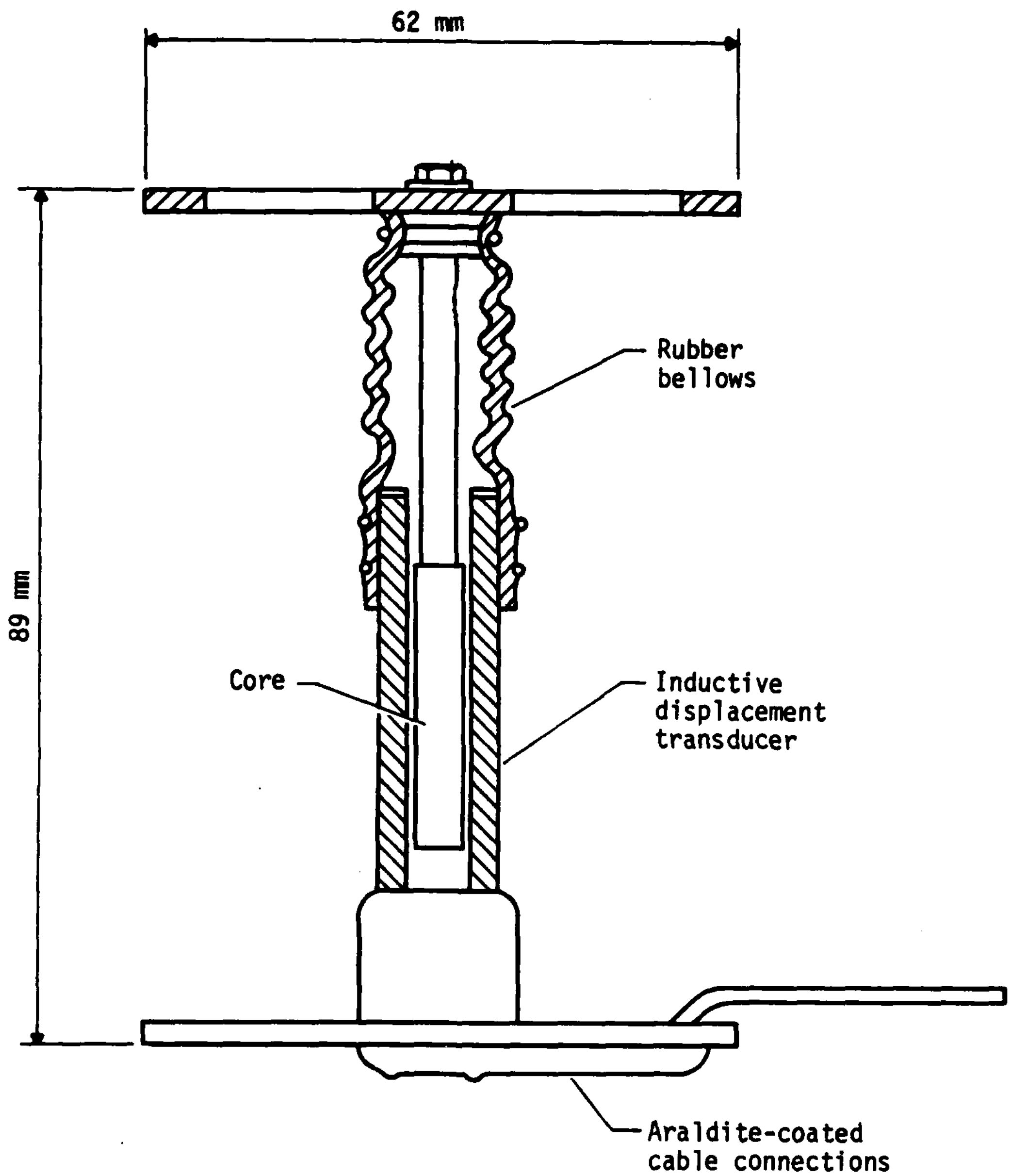


Figure 6. LVDT-Type Strain Measurement Device (Ref. 14).

Variable Displacement Transducer (LVDT). This type of device is cumbersome to install and the LVDT-type measurement may cause movement to be restricted. The strain is computed knowing the relative movement and initial spacing of the plates.

Figure 7 presents the second type of soil strain measurement device consisting of a pair of coils manufactured by Bison Instruments, Inc. The coils operate on the principle of electromagnetic inductance: one coil creates an electromagnetic field that can be sensed by the second coil which produces a voltage proportional to the distance between the coils. The output is correlated with calibration curves obtained in the laboratory with known coil spacing and movement. This device can be used to record both static and dynamic measurements. However, in dynamic applications any nonstationary metallic object within five diameters' distance may cause the electromagnetic field to be disturbed, introducing errors into the data. A similar device has been used to record lateral strains of cylindrical soil samples tested in triaxial compression apparatus (Reference 17).

For bound materials or materials capable of tensile forces, devices similar to the first type of strain device described above may be used. NMERI has had good results using an embeddable-type strain gage (Reference 18). This type of gage, shown in Figure 8, can be easily installed using various techniques and used in laboratory testing, as well as in the field. The Bison coils may also be used to measure tensile strains.

DEFLECTION GAGES

Various methods have been used to record the deflection of pavement layers under load, both static and dynamic (Reference 14). However, deflection measurement devices were not extensively researched, based on information from NMERI electronics personnel, on the incompatibility of such devices with anticipated electronic equipment.

Briefly the methods consist of displacement transducers, laser and optical systems, and velocity and acceleration transducers. With displacement

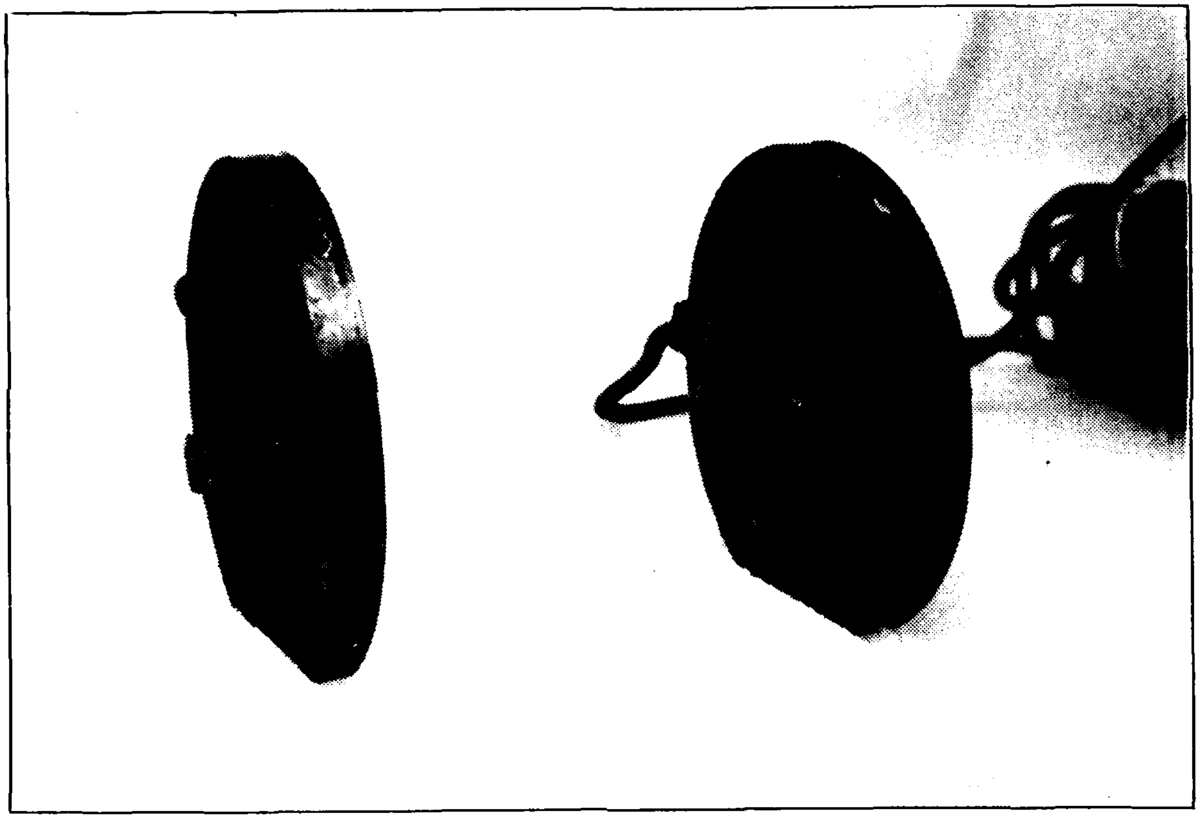


Figure 7. Bison Strain Measurement Coils.

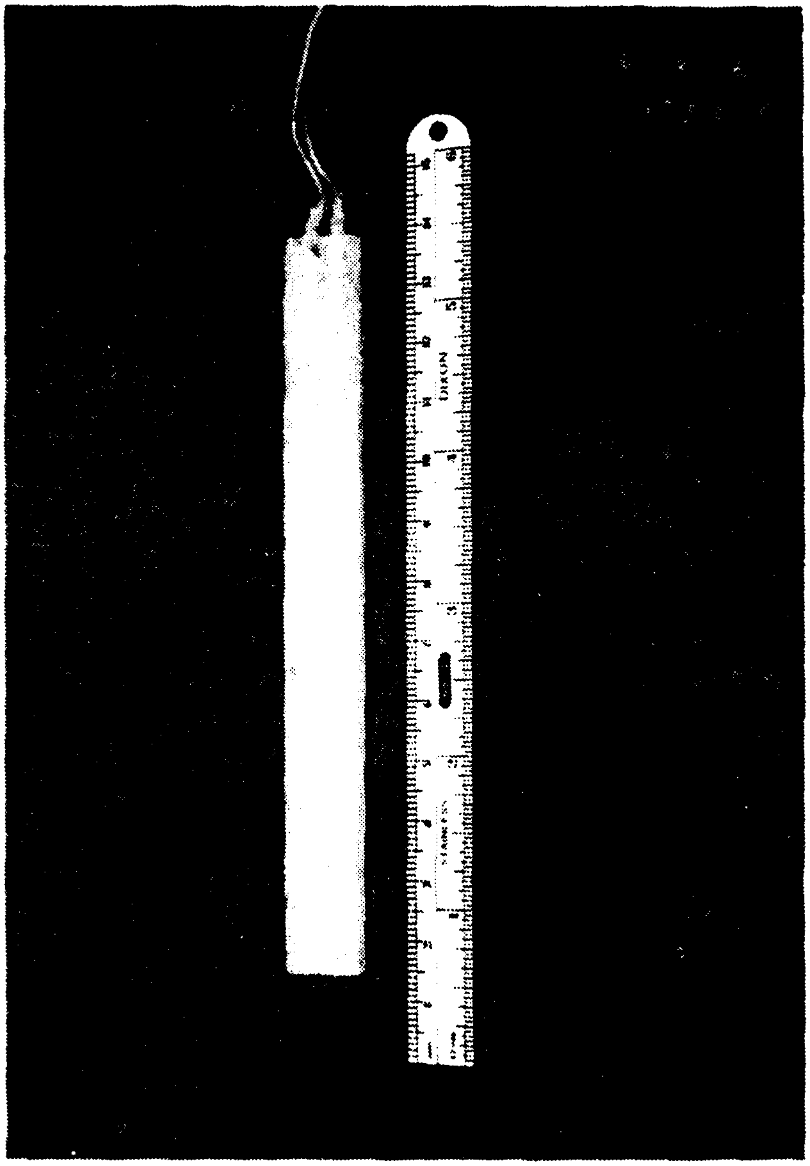


Figure 3. Embeddable Tensile Strain Gage.

transducers, the deflection of the surface is indicated and recorded via a transducer that is located between a stationary datum and the surface. If displacement of a subsurface layer is desired, the LVDT is placed on a rod and connected to a plate that is installed at the desired depth or interface location. Laser and optical systems may consist of a sophisticated rod and level survey method, or may consist of a more complicated procedure such as measuring the intensity of a reflected laser beam. Another optical system consists of photoelectric cells mounted on a frame to measure the dynamic deflection basin produced by the wheel load. Velocity and acceleration transducers can be installed at any point in the pavement system. Single integration and double integration, respectively, provide the deflection under load. However, these instruments can measure only dynamic deflections.

RECOMMENDED EQUIPMENT

After considering both the equipment available to measure stress, strain, and deflection for BDR applications, and the requirement to perform these measurements at the North Field Demonstration Test, NMERI recommended equipment to AFESC/RDCR for use in the BDR code verification instrumentation plan. The recommended equipment consisted of membrane-type pressure gages, Bison soil strain gages, and embeddable-type tensile strain gages.

Most of the membrane-type gages cited in the literature were not available commercially and were fabricated for the North Field test. Time did not allow NMERI to design and fabricate a stress gage for the test. Therefore, NMERI conducted a search for commercially available pressure gages that could be received in time to perform preliminary calibrations and evaluations. NMERI contacted Terra Tek of Salt Lake City, Utah, concerning the availability of membrane-type pressure gages installed under their supervision in various earthwork operations and dams.* Arrangements were made with Terra Tek and a pressure transducer distributor to provide all parts necessary to fabricate five membrane-type pressure gages. The parts were received at NMERI in time to perform preliminary testing that indicated dynamic overregistration response of the gage to a moving load compared to the static load. Because

*Personal communications with Mr. Mike Voegele, Terra Tek, Salt Lake City, Utah, April 25, 1980.

of the lack of time, these gages were used at the North Field test with additional gage evaluations to be performed after the test. NMERI contacted a second manufacturer of a membrane-type gage, Geokon of West Lebanon, NH, and purchased two gages for comparison with the Terra Tek gages. Requisitions were placed for three soil strain measurement devices, but the anticipated delivery date (after the date of the North Field Test) prevented their use in the test. The embeddable tensile strain gages were available in-house, but were not necessary for the North Field Test since that test did not include conventional, bound materials capable of tensile strain measurements.

To record the data, a conventional 14-track FM analog tape recorder was retained. The unknown factors of signal duration, test duration, and signal frequency content precluded the use of digitizing units and automated, minicomputer data acquisition systems, because of fast digitizing rates and the quantity of digital data that could be collected. An analog recorder recorded the actual data that could be digitized, if desired by the Eglin or Kirtland Air Force Base computer centers for more detailed analyses. In addition to the analog recorder, signal conditioning equipment and amplifiers were necessary to allow high quality data to be recorded. An Interrange Instrumentation Group (IRIG) code generator/reader placed a coded signal on the tape so that the signals could be reproduced, analyzed, and correlated to real time. The IRIG generator could be synchronized with other IRIG units or WWV time transmissions for correlating with instrumented aircraft responses.

The pressure gages (Terra Tek and Geokon) were statically calibrated in the laboratory to determine nonlinear characteristics of the voltage output with load and calibration factors. These curves were used to select the appropriate signal conditioner shunt calibration resistance for the anticipated pressure level (Appendix A). A gage was placed in a blended limestone aggregate material similar to the crushed limestone material used at North Field to evaluate a placement technique and record data for a moving wheel load over a backfilled test pit. The moving wheel load was created by a NMERI truck at a speed of approximately 10 to 15 miles per hour. Static wheel loads were also recorded. Upon comparison of the static and dynamic peak pressures indicated by the gage, dynamic pressures exceeded the static stresses by approximately 50 percent.

An effort was made to evaluate the gage output voltage as a function of frequency, but problems with the dynamic calibration equipment prevented any conclusive data to be collected. After the North Field test, an alternate approach was taken to evaluate the dynamic response characteristics of the gage utilizing digital signal processing and fast Fourier transforms (FFTs). In this method the gage was subjected to an impact load and the corresponding gage response digitally recorded by a minicomputer. An FFT of the signal was performed that provides the modulus and phase as a function of frequency. By looking at the modulus of the gage signal due to an impact load, peaks can be detected that indicate resonant frequencies of the gage when compared to troughs or lower modulus values which indicate attenuation frequencies and mean gage performance. Figure 9 shows an example of an FFT from an impact load on a pressure gage. The mean performance of the gage is shown as a dashed line. It is logical to anticipate that the gage will indicate a higher pressure compared to the mean if the frequency of the induced pressure wave corresponds to a resonant frequency. Thus, a correction factor is necessary to adjust the data to more accurately reflect the actual pressure applied to the gage.

A preliminary correction factor of one-third was developed for the data collected at the North Field test. The data multiplied by one-third resulted in the dynamic pressures being approximately 10 to 50 percent of the static stress. More detailed analyses of the North Field test data are included in Appendix B. All personnel involved with instrumentation and BDR crater performance should review the data report in Appendix B.

The Bison soil strain measurement system has been briefly described. The system consists of a measurement and calibration unit and two sensors, one transmitter, and one receiver. A carrier signal provided by the measurement unit is input to the transmitting sensor and an electromagnetic (EM) field is created in the vicinity of the sensor. The second sensor (the receiver) intercepts the EM field and produces an output voltage that is proportional to the strength of the field. The closer the receiver is to the transmitter, the

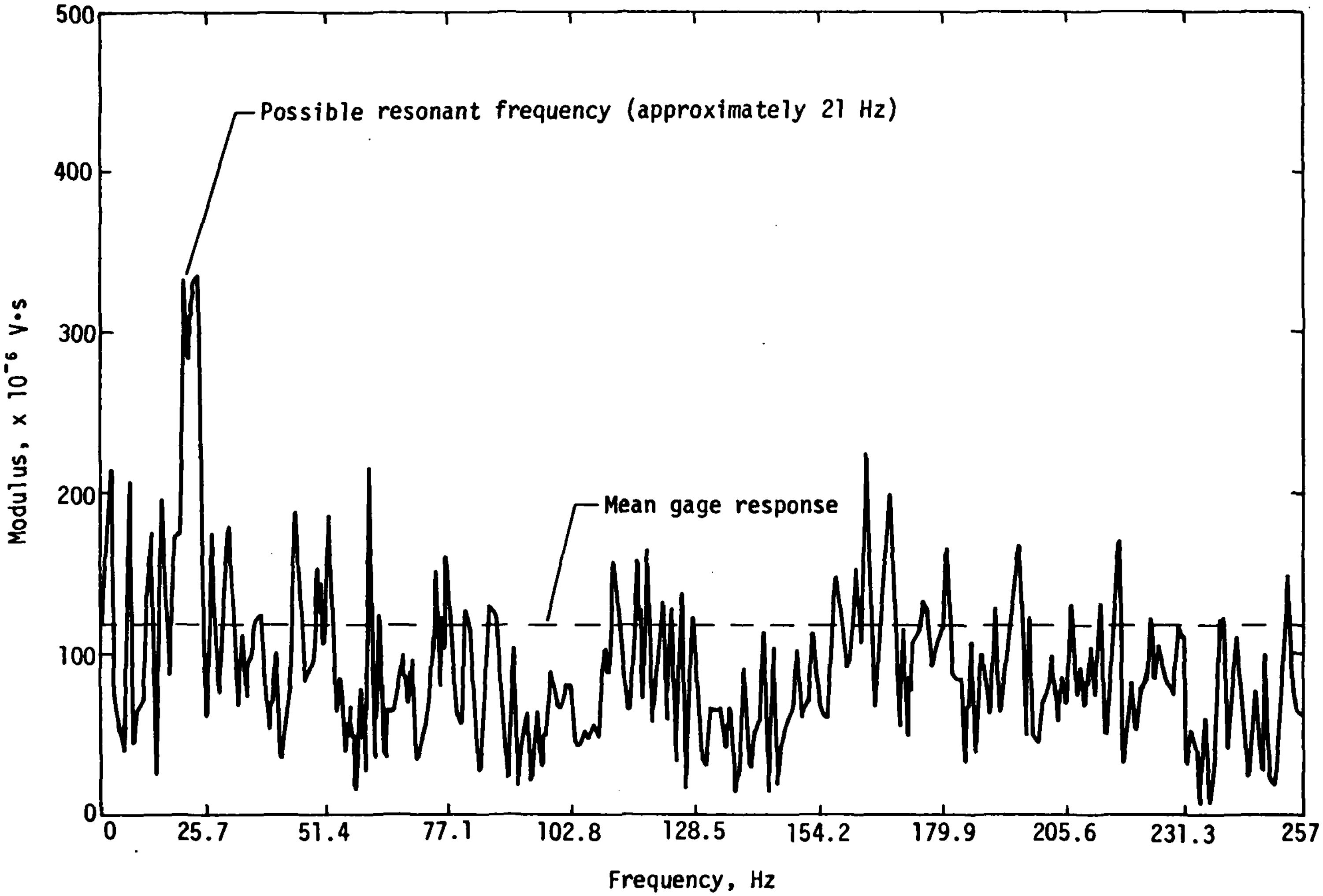


Figure 9. FFT Of Pressure Gage Output Due To Impulse Load

stronger the field and the greater the voltage produced. By correlating the voltage level with calibration curves developed in the laboratory, the spacing can be determined. If the sensors move toward or away from each other, the change in voltage is used to determine the change in spacing. Calibration data are provided in the instrumentation user's manual (Appendix A). Because the receiving sensor produces a voltage proportional to the strength of the EM field, the orientation of the sensor can cause changes in the voltage. If the sensors are not perfectly parallel or coaxially aligned with each other, the voltage will be less, indicating a closer sensor spacing than the actual spacing. These effects were assessed in the laboratory and the methods and results are presented here.

Initial calibration required that a pair of sensors be assigned to a specific measurement instrument to minimize the number of calibrations to be performed. The calibration data will vary from sensor to sensor, but these variations are estimated to be minimal when compared to the data. Ideally, a statistical analysis should be performed on the calibration data using a large number of sensors and several measurement instruments to determine whether the variation is significant enough to warrant sensor assignment to specific measurement instruments. The calibration data collected by NMERI indicated a small variation in the data. If AFESC/RDCR will be using the soil strain measurement system extensively, it is recommended that a statistical analysis of the data be performed.

The sensors were initially placed at the approximate minimum sensor spacing. Sensors were connected to the measurement instrument, Model 4101A, and the amplitude dial reading allowing the 4101A to be nulled was recorded. The sensor spacing was increased and the new amplitude dial reading for the null condition was recorded. This sequence was continued for greater spacings and for the different ranges of operation of the 4101A. To determine the sensor spacing in the field the reverse sequence was followed. The amplitude dial reading for the null condition was used with the calibration data tables in Appendix A to determine the sensor spacing.

Once the sensor spacing was established, it was necessary for optimum data collection to set the 4101A on the FM analog recorder without changing the operation range of the instrument. To accomplish this, a second calibration procedure was performed. The sensors were placed at a selected spacing and the 4101A was nulled. The amount of movement that corresponded to 40 to 80 percent of the full range capability was determined. These readings indicated that the 4101A response was nonlinear. That is, the change in voltage from 5- to 5.1-inch spacing was not the same as from 10- to 10.1-inch spacing. The output of the 4101A was most linear over the midrange of the maximum allowable movement for a particular initial spacing. Also, the data were most linear at a sensor spacing of twice the sensor diameter.

In the field after the initial spacing has been determined, the maximum strain can be obtained from the calibration data tables in Appendix A. The anticipated level of strain was used in the equations provided in the user's manual to select the calibration signal dial reading for recording the data. This allowed the data to be recorded in the midrange of the instrument and minimized the nonlinear effects.

Sensor tilt effects were evaluated by placing the sensors at a selected spacing, nulling the 4101A, and recording the corresponding amplitude dial reading. One sensor was tilted 5, 10, and 15 degrees from the parallel sensor configuration and the new amplitude dial readings that corresponded to the new null condition were recorded. These data indicated that a maximum tilt of 15 degrees caused the instrument to null at an amplitude dial reading corresponding to a position approximately 0.10 inch closer than actual sensor spacing. To determine the significance of this on the data collected, assume two field situations, A and B. In case A the sensors are 8.0 inches apart and perfectly parallel. In case B the sensors are 8.0 inches apart, but at a tilt of 15 degrees, giving the indication that the sensors are

7.9 inches apart. Assume the sensors will move 0.1 inch closer. The computed strain for cases A and B are calculated as

$$\text{Case A, } \varepsilon = \frac{0.1}{8.0} = 12.5 \times 10^{-3}$$

$$\text{Case B, } \varepsilon = \frac{0.1}{7.9} = 12.7 \times 10^{-3}$$

The error is approximately 1.3 percent. The most significant effect on the data would occur when the sensors move and tilt at the same time. This would indicate a greater strain than actually occurred. This effect on the data can be minimized through periodically recording the static position of the sensors by nulling the 4101A, determining the new spacing, and calculating new calibration amplitude settings.

A similar effect is caused by a coaxial offset of the two sensors. At a spacing of 1.5 diameters, a 1-inch offset causes a 0.50-inch error in the calculated spacing. The error is reduced 0.10 inch at a 2.5-diameter spacing. At the recommended spacing of 2.0 diameters, the error is approximately 0.1 to 0.2 inch. Again, coaxial offset effects can be reduced by nulling the 4101A periodically and calculating new calibration amplitude settings, if sensor offset is suspected during a test.

Additional errors can be created in the data by recording measurements, when the 4101A unit is not properly warmed up or with low power battery operation. Before any measurements are made, the 4101A should be operated for 10 to 15 minutes. After every test, the units should be connected to the charging devices to eliminate low power operation. It is possible to develop an alternate external power supply to allow continual operation of the measurement units.

If the cable connecting the sensors to the 4101A measurement unit is very long, the calibration data tables provided in Appendix A will be slightly in error. The calibrations were performed with approximately 6 feet of cable.

Increasing the cable length to 1000 feet would cause calculation of the sensor spacing to be 0.3 inch greater than the actual spacing. For reasonably long cables (i.e., less than 500 feet), the calibration data are estimated to provide sensor spacing to within 0.1 inch of the actual spacing. It should be emphasized that if the cable has splices or solder joints the calibration data, with respect to the initial sensor spacing determination, will be calculated to be greater than the actual spacing.

If all possible errors occur during a test (simultaneous compression and tilting, a 1-inch coaxial offset, long cable length, and poor quality cables), an error of up to 100 percent may occur. If measurements are periodically made to remove the tilting and misalignment effects, the data can be accurate to within 10 percent.

The embeddable tensile strain gages were calibrated at the factory and the calibration data are printed on the shipping box. Equations are provided in the user's manual (Appendix A) to determine the necessary information for recording the data. The tensile strain gages are unaffected by temperature and are accurate to within less than 1 percent, if the gage is adequately bonded to surrounding material.

SECTION III

CONCLUSIONS

Instrumentation consisting of pressure and strain measurement devices, and associated equipment for recording static and dynamic data have been provided to AFESC/RDCR for verification of the BDR computer code. The pressure measurement devices were used successfully at the North Field Demonstration Test, North Field, South Carolina, during August 1980 to record data in a repaired bomb crater trafficked by aircraft and a load cart. Appendix B contains a report for review. All equipment and technical information have been transferred to AFESC/RDCR, allowing additional data on repaired bomb craters to be collected and correlated with predicted responses from the BDR code.

Based on interpretation of the results from the North Field test, the soil pressure gages obtained for the project are adequate for static and pseudostatic (i.e., less than 5 Hz frequency content) load applications. These gages were selected because of their capability to average pressure concentrations over the large surface area of the gage. However, with controlled placement techniques and procedures it is possible to utilize a different type of pressure gage and eliminate the poor dynamic response characteristics and associated problems. It is recommended that a diaphragm-type strain gage be tested and evaluated for use in BDR applications.

The Bison strain measurement system is capable of providing adequate results based on laboratory calibrations. Standard procedures for collecting and analyzing data need to be developed concurrently with field testing and system utilization. The recommended embeddable-type tensile strain gages will provide accurate tensile strain data if the gages are adequately bound with the surrounding material.

Not all of the recommended equipment is required for every test. The test coordinator must assess the critical test parameters and select the equipment providing the most applicable data to evaluate test performance. These data can then be correlated for verification with the BDR code predictions.

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REFERENCES

1. Baird, Glenn T., *Bomb Damage Repair Code for Prediction of Repaired Crater Performance*, ESL-TR-80-69, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, September 1980.
2. Crawford, John E., *An Analytical Model for Airfield Pavement Analysis*, AFWL-TR-71-70, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, 1972.
3. Nielsen, John P., *AFPAV Computer Code for Structural Analysis of Airfield Pavements*, AFWL-TR-75-151, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, 1975.
4. Yoder, E. J., and Witczak, N. W., *Principles of Pavement Design*, John Wiley and Sons, Inc., New York, 1975.
5. Triandafilidis, G. E., "Soil Stress Gage Design and Evaluation," *Journal of Testing and Evaluation*, Vol. 2, No. 3, American Society for Testing and Materials, 1974.
6. Peaker, K. R., "A Hydraulic Earth Pressure Cell," *Instruments and Apparatus for Soil and Rock Mechanics*, ASTM STP 392, American Society for Testing and Materials, 1965, pp. 75-81.
7. Lazebnik, G. E., Smirnov, A. A., and Ivanov, D. G., *A Set of Instruments and Equipment for Measuring Soil Pressure*, Osnovaniya, Fundamenty i Mekhanika Gruntov, No. 2, March-April 1973, pp. 16-19.
8. Tyler, R. G., "A Vibrating Wire Soil Pressure Gauge," *Tunnels and Tunnelling*, November 1976, pp. 73-78.
9. Carder, D. R., and Krawczyk, J. V., *Performance of Cells Designed to Measure Soil Pressure on Earth Retaining Structures*, TRRL Laboratory Report 689, Transport and Road Research Laboratory, 1965.
10. O'Rourke, John E., "Soil Stress Measurement Experiences," *Journal of Geotechnical Engineering Division*, ASCE, Vol. 104, No. GT12, American Society of Civil Engineers, December 1978.
11. Blackwell, P. S., and Soane, B. D., "Deformable Spherical Devices to Measure Stresses Within Field Soils," *Journal of Terramechanics*, Vol. 15, No. 4, 1978, pp. 207-222.
12. Boor, D., *Development of Instrumentation for In Situ Soil Measurements*, AFWL-TR-78-59, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, October 1978.
13. Trollope, D. H., and Lee, I. K., "The Measurement of Soil Pressures," *Proceedings*, Fifth International Conference on Soil Mechanics and Foundation Engineering, Vol. II, Paris, 1961, pp. 493-499.
14. Brown, S. F., *State-of-the-Art Report on Field Instrumentation for Pavement Experiments*, Transportation Research Record No. 640, Transportation Research Board, 1977, pp. 13-28.

15. Selig, E. T., and Grangaard, O. H., Jr., "A New Technique for Soil Strain Measurement," *Materials Research and Standards*, Vol. 10, No. 10, American Society for Testing and Materials, Philadelphia, Pennsylvania, November 1970, p. 19.

16. Springston, P. S., *Traffic Testing of a Fiberglass-Reinforced Polyester Resin Surfacing for Rapid Runway Repair*, Technical Note No. N-1572, Civil Engineering Laboratory, Port Hueneme, California, February 1980.

17. Khan, Mozammel, and Hoag, Dean L., "A Noncontacting Transducer for Measurement of Lateral Strains," *Canadian Geotechnical Journal*, Vol. 16, Ottawa, Canada, 1979, pp. 409-411.

18. Cassino, Vincent, *Evaluation of Liquid Binders for Airfield Bomb Damage Repair*, AFCEC-TR-75-25, Air Force Civil Engineering Center, Tyndall Air Force Base, Florida, September 1975.

APPENDIX A
INSTRUMENTATION USER'S MANUAL

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SECTION I

SYSTEM OVERVIEW

1.1 INTRODUCTION

This manual is designed for use by AFESC technicians to implement and maintain the instrumentation procured by NMERI under Contract No. F29601-76-C-0015, Subtask Statement 5.15, Instrumentation Plan for Bomb Damage Repair Computer Code Verification. The scope of the subtask was to review and recommend equipment that could be used to measure and record static and dynamic responses of a repaired bomb crater due to aircraft, simulated aircraft (load cart), and static loads. Measured responses were to be compared with calculated responses from the NMERI Bomb Damage Repair (BDR) computer code for verification of the code. The instrumentation consists of stress and strain measuring devices designed for use within the crater, as well as signal conditioning and an analog tape recorder located in an area remote from the crater. Data recorded on the analog tape can be reproduced and recorded on a strip chart recorder for on-site evaluation or sent to a data reduction facility for a more detailed analysis.

1.2 SYSTEM COMPONENTS

- 1 ea. Bell and Howell CPR 4010 Portable Instrumentation Recorder
- 1 ea. Datum Model 9300 Time Code Generator/Reader
- 1 ea. Datum Model 9241 Tape Search Unit with Cable
- 10 ea. B&F Model 1-700SG Signal Conditioners
- 10 ea. B&F Model 702A-10D Differential Amplifiers
- 2 ea. B&F Model RW2229-7 Rack Mounts with Mating MS Connectors.
- 3 ea. Bison Model 4101A Soil Strain Gage Instruments
- 10 ea. Bison 4-inch Sensors
- 10 ea. Bison 2-inch Sensors

SECTION II

OPERATIONS

2.1 GAGE INSTALLATION

2.1.1 <u>Terra Tek and Geokon pressure gage installation</u>--Both the Terra Tek and Geokon gages are bladder-type pressure gages that measure in situ soil pressure by measuring the changes in the fluid pressure within the bladder. The Terra Tek gages are approximately 12 inches by 12 inches and 0.125-inch thick. The Geokon gages are approximately 9 inches in diameter and 0.5-inch thick.

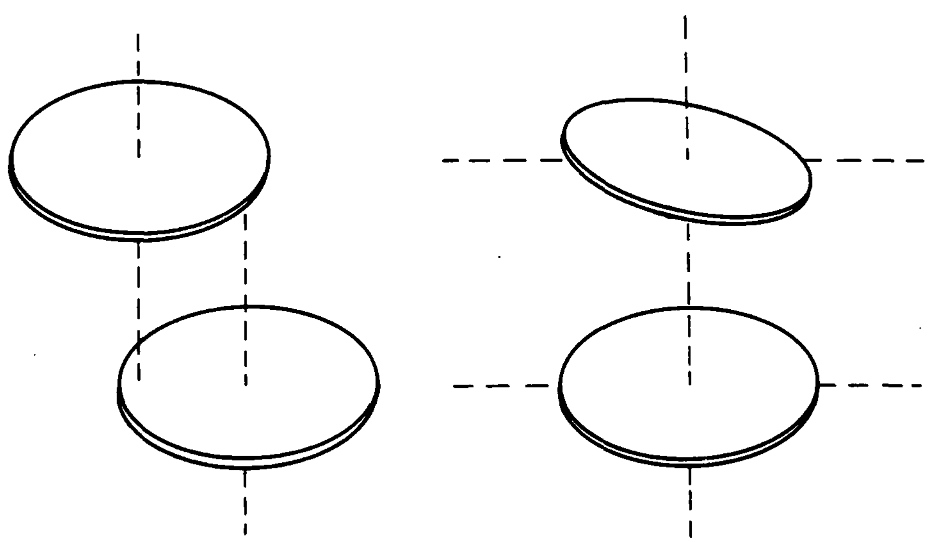
The gages should be located on approximately 1.5 inches of a sandy-silt (or finer) noncohesive material in the test area. Press the gage firmly into the sandy silt to ensure that the gage is seated. The cables should be protected as well as possible to prevent damage and there should be a minimal length of cable in the repair area. Avoid abrupt changes in direction of the cable. After the gages are located, place another 1.5 inches of the sandy-silt material on top of the gages. Backfill the test area by hand to approximately 1 foot above the gages to reduce any possibility of damage to the gages and cables. In selecting the gage locations, no two gages should be placed closer than 2 feet horizontally or 4 feet vertically to minimize the effects of the sandy-silt material on the stress-strain field developed in the backfill material.

2.1.2 <u>Bison soil strain gage installation</u>--The Bison Instruments' soil strain gages are inductance-type gages consisting of two sensors. One sensor is connected to a transmitting circuit of the instrument and creates an electromagnetic field in the immediate vicinity of the gage. The second sensor acts as a receiver for the instrument that produces a voltage proportional to the distance from the transmitter.

Because of difficulties related to placing the sensors at a predetermined spacing, it is recommended that the sensors be placed at an approximate distance and then determine gage separation using the calibration data for that sensor pair and instrument.

The sensors are sensitive to coaxial offset (Figure A-1a) as well as to angular rotational effects (Figure A-1b). Therefore, care must be taken to ensure that the sensors are parallel and centered. Both sensors must face the same direction along their common axis or the Bison instrument will not null.

One installation method requires a hand level and plumb bob, using the plumb bob and two established bench marks to center the sensors and the level to ensure their horizontal orientation. After preparing a flat surface area at the desired depth, use the plumb bob, bench marks, and level to firmly seat the lower sensor (the receiver) in the soil. Backfill and compact by hand to avoid possible damage to and movement of the sensor. Add sufficient material to equal the approximate sensor spacing and place the top sensor (the transmitter) using the same method as for the lower sensor. Phase and amplitude are then nulled and the separation of the sensors can be obtained from the calibration data using the AMPLITUDE and RANGE dial readings.



a. Coaxial offset

b. Angular rotation

Figure A-1. Geometric Sensitivity.

Another procedure for installation utilizes a wooden dowel rod inserted through the center of the sensor pair to ensure that the sensors are coaxially aligned during placement.

The first sensor should be placed at the desired depth, as close to horizontal as possible, using a hand or bull's-eye level. A wooden dowel rod is inserted through the center of the sensor and is marked at its surface. The desired sensor spacing or gage length is measured from this mark at the top of the sensor and marked on the dowel. This second mark will determine the position of the second sensor when the dowel is located even with its upper surface. Backfill and compact the material around the first sensor, with the dowel in place normal to the sensor surface, using care not to disturb or displace it.

Slip the second sensor over the dowel and check for proper gage length. Proper gage length is reached when the second mark for the sensor spacing is located even with the top of the second sensor. Ensure that the second sensor is seated firmly in the soil and is level. Carefully remove the dowel, recheck for horizontal orientation, and complete the backfill using care not to displace the sensor. During this procedure, bench marks should be used and recorded to locate the gage within the repair area as an aid in recovery and data reduction.

Any cable attached to a gage should be protected from traffic and strains created by the test conditions. These conditions can cause cable breakage or movement of the gage resulting in lost or erroneous data. Within the repair area flexible plastic hose or pipe can be used to relieve strain and possible movement of the gage. Loops of cable placed within the hose or pipe will help guard against cable breaks. Cable trenches that are inclined to just below the surface protect cables from pedestrian and vehicle traffic. Cables should never be bent, bound, loaded, or twisted in such a manner that a cable break or excessive strain may occur when external forces are applied to the system.

2.1.3 Embeddable strain gage installation--The embeddable strain gages are used to determine tensile strains in materials that can readily bond to the strain gage. The gages may be placed in materials such as concrete, asphalt, or epoxy as long as the gage is capable of deforming with the material. Bonding can be increased by cutting small notches in the side of the gage. Locations and placement techniques of the gages will vary depending on the test plan, number of gages, and type of measurement. Gage locations will be selected by the test coordinator or director. For materials capable of tensile stress and strain, gages may be located near the point at which the tensile strength of the material may be exceeded.

However, in selecting a placement technique consideration must be given to the stress and strain produced in the material due to the testing conditions. No materials used in the placement of the gage should cause changes in the behavior of the material being tested. For example, do not use reinforcing steel bars (rebar) to support the gage in an unreinforced concrete material. This would cause stress concentrations to develop at the interface between the concrete and rebar and may result in recording inaccurate data.

One technique uses a high-strength nylon string or very thin wire to support the gage between two wooden dowel rods that would position the gage approximately in the desired location. This technique utilizes dowels that have strength properties much less than those of the concrete being tested. By supporting the gage on a string, the stress/strain field is disturbed insignificantly; this technique also allows the dowels to be located at some distance from the gage.

Other techniques may be used, but the above factors should be considered before adopting any particular procedure.

2.2 SIGNAL CONDITIONING AND RECORDING

2.2.1 Interconnections and front panel controls--Connect the transducers and bridge completion resistors to the terminal strips located on the rear door of the equipment rack. The terminal strips are connected by cables to the inputs of the signal conditioners through the RW2229-7 rack adaptor. The inputs of the rack adaptor are A95-type connectors (MS 2102A-20-27S) labeled J-2211 through J-2220. These connectors contain all excitation, calibration, and signal connections needed for the transducers.

2.2.2 Front panel controls for 1-700SG signal conditioners--

BALANCE CONTROL--The balance control is used in conjunction with the limit resistor to balance the residual offset of the transducer.

SPAN CONTROL--The span control adjusts the individual power supplies used for excitation to the transducer. In the constant-voltage mode, a clockwise rotation results in an excitation voltage increase.

OUT MONITOR--The output monitor pushbutton connects the conditioner output to the monitor buss (connector J-2221, MS 1002A-16-15).

CAL SWITCH--The cal switch allows a shunt resistor to be switched across an arm of the bridge for an output calibration level.

The outputs of the signal conditioners via the rack adaptor are cabled from connectors J-2201 through 2210 (MS-3102E-10SL) to the inputs of the differential amplifiers through their rack adaptor and connectors J-2211 through 2220 (MS-3102A-20-27S).

2.2.3 Front panel controls for 702A-10D differential amplifiers--

GAIN CONTROL--Fixed gains of 1, 3, 10, 30, 100, 300, or 1000 can be selected on the rotary switch when the vernier is not in use.

ZERO CONTROL--This pushbutton, when depressed, shorts both inputs of the differential amplifier to common, which allows the operator to zero the internal offset of the amplifier. When released, both inputs are connected to their respective input terminals.

ZERO ADJUST CONTROL--This control provides for the external adjustment of the amplifier's offset.

VERNIER ON-OFF CONTROL--When in the ON position, this control permits the operator to select a discrete gain rather than a fixed gain setting.

VERNIER ADJUST CONTROL--When the vernier control is in the ON position, it allows the gain to be adjusted from 1 to 3.5 times that shown on the fixed gain control.

The outputs from the amplifiers are taken from connectors J-2201 through J-2210 of the rack adaptor and cabled with RG58 BNC to the record inputs of the tape machine and to the patch panel. The outputs of the time code generator (J2) and the Bison instruments are also cabled to the record inputs of the tape machine. The reproduce output of the tape machine for the time code is cabled to the time code reader (J1) for time readout in the playback mode. Other devices such as oscillographs, oscilloscopes, and strip chart recorders may be connected to the reproduce outputs.

2.2.4 Electronics operations--The following is a brief functional description of each major component of the system.

Signal conditioning--Signal conditioning becomes necessary when a transducer is not capable of producing a satisfactory output without the aid of external components such as power supplies and calibration devices. The B&F Model 1-700 signal conditioner combines a power supply, a balance control, and shunt calibration relays for transducers used in a bridge configuration.

The unit contains a removable printed circuit (PC) board front panel called a mode card. This card permits ready access to the calibration, balance, and completion networks. (Bridge completion can be made on this card, but is not recommended because of its relative complexity.) The balance control allows the initial residual imbalance of the bridge to be balanced, producing a zero output. Some full bridge transducers are prebalanced by the manufacturer with no external balance required. In this case, the balance limit resistor should be removed, disabling the balance control network and eliminating the desensitization error. The balance circuit is connected to a corner of the bridge and thus shunts two of its arms, inducing desensitization error. To reduce this error, use a balance limit resistor at least 50 times larger than the transducer resistance. The high value limit resistor will have a lesser shunting effect on the two arms of the bridge across which it is wired and will lessen the desensitization error.

Calibration of the bridge is achieved by placing a calibration resistor on the mode card, which is shunted by relay across an arm of the bridge. The resulting resistive imbalance causes a voltage to appear at the output terminals, simulating a known strain or pressure level. Refer to Section 3.1 of this manual for calculation of the calibration resistors.

The outputs of the signal conditioners are normally connected to differential amplifiers, as the bridge outputs are not of sufficient amplitude or current to drive a magnetic tape recorder or other recording devices.

Differential amplifier--The Model 702A-10D solid state differential amplifier consists of a preamplifier, a common mode attenuator, and a post-amplifier. The input range is ±10 mV to ±10 V full scale with a full-scale output of ±10 V at 100 mA. It can be operated in either differential- or single-ended input configurations, and is a wideband d.c. amplifier with gains ranging from 1 to 3500 having a high common mode noise rejection ratio. Connected to the signal conditioner, it provides sufficient drive for most recording equipment.

Magnetic tape recording--Analog tape recordings are convenient and durable for data storage. Recorded data can be reproduced many times before any noticeable degradation of the signals occurs.

Frequency modulation (FM) recording should be used whenever possible, because direct recording will not reproduce low frequency data and has a lower signal-to-noise ratio. Inputs to the tape recorder should be of sufficient amplitude to evenly distribute the data over the range of the FM recording electronics.

The Bell & Howell CPR-4010 FM recording electronics have a deviation range of ±40 percent of their center frequency. The record center frequency is automatically selected when tape speed is selected by the knob on the front panel. This center frequency also limits the bandwidth of the input data. For example, a tape speed of 7.5 in/s has a center frequency of 27 kHz and a maximum intelligence frequency bandwidth of 5 kHz, which is the IRIG wideband standard for Group 1 ±40 percent.

Deviation levels of the FM recording electronics are normally set according to the predicted levels or the shunt calibration levels. If the predicted levels are too low and the tape machine is set for maximum deviation according to that prediction, the data ranging over the prediction will be lost. The gain of the B&F amplifier set to give 20 percent FM deviation or 50 percent of bandedge for the calibration step gives a 50-percent safety margin and also provides sufficient resolution when reproduced. For wide-ranging signals, it may be desirable to double record a signal with two different deviations by paralleling two record inputs. By setting one calibration for a low deviation (30 to 40 percent) and the other for a high deviation (60 to 80 percent), one of the channels will provide resolution over the entire range.

Reproducing the signals through the FM demodulator located in the machine filters the data at the maximum intelligence frequency bandwidth. For the Bell & Howell CPR-4010, only two speeds of reproduce electronics are supplied (7.5 and 0.9 in/s). The data may be recorded at any of the selectable speeds, but must be reproduced at either 7.5 or 0.9 in/s. Reproduction of data at a speed other than the record speed will change the time base of the data.

<u>Time code generator/translator</u>--To accurately locate data recorded on tape, a time code is recorded along with the data. The time codes generated by the Datum Model 9300A IRIG generator are amplitude modulated carrier frequencies that can be read manually or automatically with accuracies of less than 1 ms for IRIG B and 0.1 ms for IRIG A. Care should be taken when selecting the type of IRIG code to be recorded, as their respective carrier frequencies are 1 kHz and 10 kHz, which may exceed the record's bandwidth.

Slow code outputs are available for reproducing a tape at a speed higher than originally recorded for easy manual readout. Codes of 1/1, 1/5, 1/10, 1/60, and one code for every 10 minutes are selectable on the front panel.

The translator, when connected to the Datum Model 9241 tape search unit, provides relay closures for the automatic calibration of the B&F signal conditioners or as NORMALLY OPEN or CLOSED closures for remote operations. The guide for the Datum tape search control unit (Attachment 2) details other functions and relay specifications.

III. DATA COLLECTION AND REDUCTION CONSIDERATIONS

3.1 SHUNT AND BISON CALIBRATIONS

To eliminate the error associated with the calibration of each component of the system, the gage calibration which represents a known strain or pressure level must be recorded prior to each test.

Using this approach, the absolute value of the output of any component has little or no meaning and only the ratio of the calibration signal to the data can be used to convert the data into useful information.

3.1.1 Shunt calibration--For resistive-type gages, an external resistance is paralleled across the gage or in a bridge configuration across one of its arms to produce a voltage output equal to a known strain or pressure. The resistor is called a shunt resistor, because it shunts the gage to create an alternate current path; this causes a different voltage output from the gage. Since the shunt resistor is connected to the gage only during calibration, it has no effect on gage output during actual testing. (The guide for the B&F signal conditioner [Attachment 2] contains an introduction to strain gage conditioning, detailing effects of wiring on calibrations.)

Shunt resistors should be selected to reasonably equal the peak predicted levels. The value of the shunt resistor can be experimentally determined by trial and error or calculated from the equations below.

$$R_{cal} = \frac{1}{4}\left[\frac{1000RG}{P\ E_0} - 2RG\right] \tag{A-1}$$

$$R_{cal} = \left[\frac{RG \times 10^6}{\varepsilon KN}\right] - RG \tag{A-2}$$

$$\varepsilon = \frac{RG \times 10^6}{NK[R_{cal} + RG]} \tag{A-3}$$

where

ε = strain in microinches per inch

N = number of active arms

K = gage factor

RG = resistance of the strain gage or transducer element in ohms

R_{cal} = resistance of the shunt calibration resistor in ohms

E_0 = transducer full-scale output in millivolts per volt

P = percentage of full scale expressed as a decimal

Since the calculated resistance is normally not readily available as calculated from Equations A-1 or A-2, use this resistance to choose a close substitute. This substitute resistance can then be used in Equation A-3 to determine the output level of the calibration.

3.1.2 Bison calibrations--Since the Bison calibrations (Attachment 3) are for maximum linear output, the peak predicted levels of strain should be chosen to equal approximately one-half of the full-scale or calibration output. The calibration output from the Bison device is a positive voltage indicating tension. Normal signal output will be a positive voltage for tension and a negative voltage for compression. Dynamic measurements for small strains can be assumed to be linear, but for large strains the output may become nonlinear.

3.2 METHODS FOR MAKING HARD COPY RECORDS

To review and reduce the data stored on tape, a hard copy is usually needed. Hard copy records are graphs, plots, or photographs that show relative amplitude versus time of a signal and contain the calibration in some form for scaling purposes.

A photograph of an oscilloscope display provides a relatively quick method for acquiring a hard copy, but the resolution of both axes is somewhat compressed and limited. Calibration of the oscilloscope is also a problem, because the trace must be calibrated according to the calibration step for that signal. Although this method has its drawbacks it is nearly the only method that can be used to capture high-frequency data in the field.

Multichannel quick-look recorders such as pen and ink, heated stylus, or oscillograph-type recorders will produce a permanent record and normally will provide sufficient resolution for field work. The pen and ink and heated stylus recorders have relatively low frequency responses (on the order of hundreds of hertz). The output is normally of higher quality than that of the oscillograph and is a permanent record. The oscillograph has a higher frequency response (on the order of thousands of hertz), but the record's light sensitive paper will fade when exposed to room light over a period of time. There are methods for developing the record with chemicals to make it permanent, but these methods would be impractical for field use.

High speed analog-to-digital conversion is a method used in data reduction facilities. When the data tape is sent to a data reduction facility, an analog-to-digital conversion can be made. Once in digital form, the data can be scaled and plotted by computer.

3.3 MATERIAL AND ALIGNMENT EFFECTS ON CALIBRATION DATA

The separation of the sensors is detected by means of electromagnetic coupling; therefore, anything that interferes with this coupling will change the output of the Bison device.

In media containing high ferrous metal concentrations, a special calibration may be required by placing the sensors in samples of the material. To determine the need for such a calibration, place a sample between the sensors and note the change in readings of the amplitude dial when the instrument is nulled. Metal objects in motion present a different problem, because they will affect the output of the Bison device during a dynamic test without significantly disturbing the static results. To minimize these effects, the transmitter of the sensor pair should be placed nearer to the metal than the receiver with a separation of at least five sensor diameters.

Initial sensor spacing is determined normally by nulling the Bison Instruments Model 4101A in the appropriate range and then using the amplitude dial setting and calibration data to determine the approximate spacing. By using this method, however, errors are introduced due to placement techniques and cable lengths.

Coaxial offset and angular rotation of the sensors during placement will cause an error in determining spacing. For an angular rotation of less than 15 deg, the error is less than 0.2 inch. Rotation causes the actual gage spacing to appear shorter. Coaxial offset error is dependent on gage spacing with its effects lessening as gage spacing increases. For a gage length of 1.5 sensor diameters and an offset of 1 inch coaxially, an error of approximately 0.5 inch will occur. At 2.5 sensor diameters the error is reduced to 0.1 inch.

Differences in cable length will cause the device to register a longer or shorter gage length than actually exists. For 1000 feet of cable, the gage length appears to be 0.3 inches longer than it would be for a 6-foot cable. This error, however, is not a linear relationship and therefore is harder to evaluate. For this reason, it is recommended that the sensors be calibrated with the type and length of cable to be used in the field test. (Note that the calibration data supplied in this manual were performed with 6-foot cables.)

ATTACHMENT 1
SYSTEM CHECKOUT

The following procedure should be followed for initial system checkout as well as for a routine check before each test. Refer to the individual guides (Attachment 2) for more complete checkout procedures and troubleshooting guides. The system is illustrated in Figure A-2.

1. Connect the equipment rack to a standard three-prong 110-V a.c., 60-Hz power outlet using the power cable attached to the rack.

Note: A 30-minute warm-up period is recommended to allow the electronics to stabilize before setup.

2. Apply power to the rack by engaging the circuit breaker located in the rear of the rack. Turn on pieces of equipment with individual power switches. The blower and the two racks of B&F equipment are hard-wired to the circuit breaker and are powered when the breaker is engaged.

3. Connect a dummy gage (a resistive substitution for the actual gage) to the terminal strips located on the rear door of the rack. For checkout during a field test, the actual gages would be connected to their respective signal conditioners and amplifiers through these terminal strips.

4. Check the output of each signal conditioner and amplifier for proper excitation voltage, balance, and calibration using a digital voltmeter and an oscilloscope.

Note: A new or degaussed tape must be used during any recording process. Erase capabilities are not provided by the tape machine. Recording on a previously recorded tape destroys the original recording, as well as adding a noticeable amount of error to the data on the second recording.

5. Using the procedure in the guide for the Bell and Howell tape machine (Attachment 2), set the center frequencies and deviations for each channel to be used on the tape machine (FM recording).

6. Make the necessary connections between the gage, signal conditioners, amplifiers, time code generator, and tape machine.

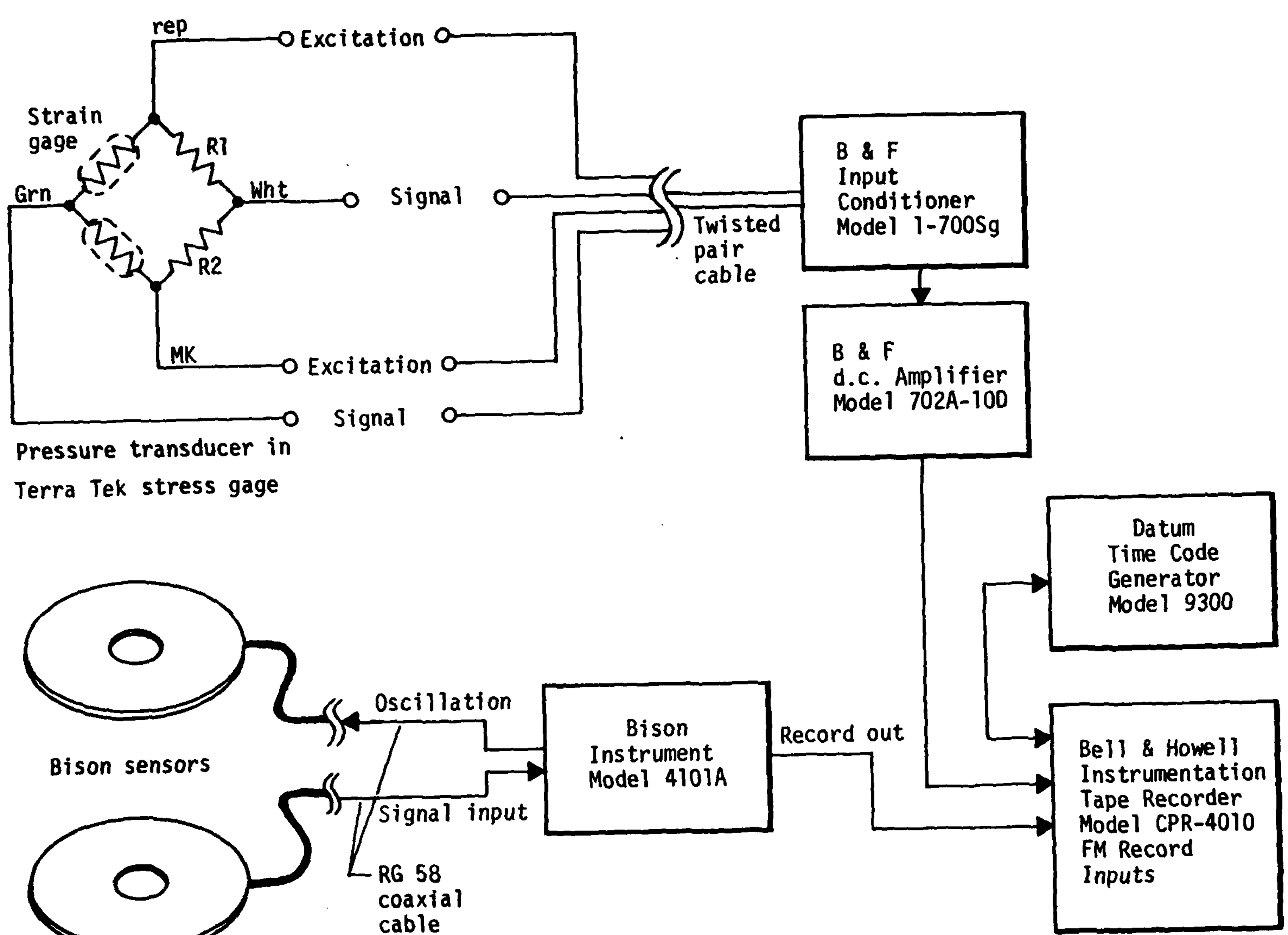


Figure A-2. System Components.

7. Start the tape machine, place it in the record mode, and monitor the outputs of the B&F amplifier and recorder for each channel used. There will be a time lag between the outputs of the amplifier and recorder. This does not affect the recorded data; it is due to the record-to-reproduce head spacing and depends on tape speed (i.e., the slower the tape speed, the farther the recorder output lags behind the input). Calibrate each channel to ensure that the signals are being recorded and reproduced at the proper levels.

8. Set the Datum IRIG generator according to the guide (Attachment 2) for the time and date desired and monitor its input to the tape machine. The deviation of this channel should be set in the range of 75 to 100 percent of bandedge, but not high enough to clip or otherwise distort the waveforms. Record 2 to 3 minutes of timing while monitoring the output. Rewind the tape and play it back to the time code reader; verify that it is operating correctly.

9. Automatic calibration for the B&F conditioners is achieved by using the Datum tape search unit. Connect a BNC cable from the relay output to the battery output located on the patch panel. Enter the start and stop times on the thumbwheel switches located on the tape search unit and press SEARCH/START and FWD controls to enable the sequence to begin. When the IRIG generator reaches the start time, the interval light on the tape search unit will light up and the relay will close, calibrating all conditioners at once. When the stop time is reached, the interval light will extinguish and the relay will open, indicating the end of the calibration sequence.

10. Attach cables from the output of the Bison Instruments Model 4101A directly to the record inputs of the tape machine. To select the sensitivity required on the Bison instrument, set the calibration signal dial to a setting that will give approximately twice the predicted strain level. Then adjust the sensitivity control to give full-scale output while in the calibrate mode. For example, a 4-inch sensor pair spacing is 8 inches and the predicted strain is 8,000 microstrain. The calibration tables show that while 100-percent or full-scale deflection equals 37,000 microstrain, the data were taken at standard sensitivity, or a calibration setting of 500, would give 18,500 microstrain at full-scale deflection (roughly twice the expected value).

11. Set the tape machine deviation for the channels to be used with the Bison equipment to equal 90 percent of bandedge for the calibration level. Repeat Step 7 for these channels.

ATTACHMENT 2
TROUBLESHOOTING AND MAINTENANCE GUIDE

Listed below are the individual troubleshooting and maintenance guides for the system components. These guides are written and produced by the manufacturers and are included with the equipment. The specific sections, pages, and tables included in the listing indicate areas of special attention that are referred to in the preceding text.

- Datum Time Code Generator/Translator Model 9300A
  Section VI pages 1-3, Section VII pages 1-26.
- Datum Tape Search Control Unit Model 9241
  Section V pages 1-2, Section VIII pages 1-20.
- B&F Signal Conditioners Model 1-700
  Section 6 pages 22-24, Section 8.
- B&F Differential Amplifier Model 702A-10D
  Sections 6 and 8.
- B&F Power Supply Model 15-200K
  Section 4 pages 33-39, Section 5.
- B&F Rack Adaptor Model RW2229
  Sections 4 and 5.
- Bell and Howell Tape Machine Model 4010

System:	Table 5-37
Tape Transport:	Table 5-34
FM Record Amplifier:	Table 5-15
FM Reproduce Amplifier:	Table 5-14
Voice Log:	Table 5-5

- Krohn Hite Variable Electronic Filter 3320 Model #23
  Section 4 pages 18-22.

To find the actual Bison sensor spacing and standard sensitivity full-scale microstrain from the tables in Attachment 3, use the following equations.

1. To find the actual sensor spacing for a given measured amplitude dial and null setting, use

$$AS = LD + (AA - LA)ID$$

$$AE = LE + (AA - LA)IE$$

where

AA = actual measured amplitude dial reading
LA = next lower amplitude dial reading listed on the table
LD = sensor spacing from the table for LA
ID = inches/dial reading from the table for LA
LE = full-scale microstrain from the table for LA
IE = microstrain/dial reading from the table for LA
AS = corrected sensor spacing in inches
AE = corrected microstrain full-scale standard sensitivity

2. To find the calibration signal dial setting for a given predicted microstrain and to set full-scale microstrain equal to twice that of the predicted level, use

$$CAL = \frac{2000(EP)}{AE}$$

where

AE = corrected microstrain full-scale standard sensitivity
EP = predicted microstrain
CAL = calibration setting required to produce the predicted level for the given range and spacing

Select a setting close to the CAL that is a whole number. Then recalculate the calibration microstrain value that the calibration step will represent.

$$Acal = \frac{AE(CDS)}{2000}$$

where

Acal = actual calibration value in microstrain, when the CAL dial is set to the selected value
CDS = selected CAL dial setting
AE = corrected microstrain full-scale standard sensitivity

ATTACHMENT 3

BISON CALIBRATION TABLES

****
BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 2*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
365.0	3.702	.002	30805.	47.
370.0	3.712	.002	31039.	47.
375.0	3.721	.002	31273.	47.
380.0	3.730	.002	31507.	47.
385.0	3.740	.002	31741.	47.
390.0	3.749	.002	31975.	47.
395.0	3.758	.002	32209.	47.
400.0	3.767	.002	32443.	47.
405.0	3.777	.002	32677.	47.
410.0	3.786	.002	32910.	47.
415.0	3.795	.002	33144.	47.
420.0	3.805	.002	33378.	47.
425.0	3.814	.002	33612.	47.
430.0	3.823	.001	33846.	34.
435.0	3.827	.002	34015.	34.
440.0	3.836	.002	34185.	34.
445.0	3.846	.002	34356.	34.
450.0	3.856	.002	34528.	35.
455.0	3.866	.002	34701.	35.
460.0	3.876	.002	34874.	35.
465.0	3.886	.002	35049.	35.
470.0	3.896	.002	35224.	36.
475.0	3.906	.002	35405.	59.
480.0	3.916	.002	35701.	59.
485.0	3.926	.000	35996.	36.
490.0	3.927	.002	36176.	36.
495.0	3.938	.002	36357.	36.
500.0	3.949	.002	36539.	37.
505.0	3.959	.002	36722.	52.
510.0	3.970	.002	36983.	63.
515.0	3.981	.002	37300.	63.
520.0	3.992	.002	37616.	63.
525.0	4.003	.002	37933.	38.
530.0	4.014	.002	38123.	38.
535.0	4.024	.000	38313.	38.
540.0	4.025	.002	38505.	39.
545.0	4.037	.002	38698.	47.
550.0	4.048	.002	38934.	77.
555.0	4.060	.002	39318.	77.
560.0	4.072	.002	39701.	77.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 2*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
565.0	4.084	.002	40084.	77.
570.0	4.096	.002	40468.	77.
575.0	4.107	.002	40851.	77.
580.0	4.119	.002	41234.	77.
585.0	4.131	.002	41618.	77.
590.0	4.140	.002	42001.	77.
595.0	4.152	.002	42384.	69.
600.0	4.165	.002	42731.	83.
605.0	4.177	.002	43148.	83.
610.0	4.190	.002	43566.	83.
615.0	4.202	.002	43983.	83.
620.0	4.215	.002	44400.	83.
625.0	4.227	.001	44817.	45.
630.0	4.231	.003	45042.	45.
635.0	4.245	.003	45267.	45.
640.0	4.258	.003	45493.	65.
645.0	4.272	.003	45818.	94.
650.0	4.285	.003	46287.	94.
655.0	4.299	.003	46757.	47.
660.0	4.313	.003	46991.	65.
665.0	4.326	.001	47314.	99.
670.0	4.332	.003	47808.	99.
675.0	4.347	.003	48301.	99.
680.0	4.362	.003	48794.	99.
685.0	4.376	.003	49287.	99.
690.0	4.391	.003	49781.	99.
695.0	4.406	.003	50274.	99.
700.0	4.420	.001	50767.	99.
705.0	4.425	.003	51260.	99.
710.0	4.441	.003	51753.	205.
715.0	4.457	.003	52777.	95.
720.0	4.473	.003	53251.	95.
725.0	4.489	.003	53725.	95.
730.0	4.505	.003	54199.	95.
735.0	4.521	.002	54673.	95.
740.0	4.531	.003	55148.	116.
745.0	4.548	.003	55725.	94.
750.0	4.565	.003	56193.	94.
755.0	4.582	.003	56661.	94.
760.0	4.599	.003	57128.	94.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 2*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
765.0	4.616	.003	57596.	58.
770.0	4.633	.004	57884.	58.
775.0	4.651	.004	58173.	83.
780.0	4.669	.004	58588.	114.
785.0	4.687	.004	59158.	114.
790.0	4.704	.004	59728.	114.
795.0	4.722	.001	60298.	114.
800.0	4.730	.004	60867.	93.
805.0	4.749	.004	61332.	122.
810.0	4.769	.004	61939.	122.
815.0	4.789	.004	62547.	122.
820.0	4.808	.004	63154.	122.
825.0	4.828	.003	63762.	122.
830.0	4.845	.004	64370.	109.
835.0	4.866	.004	64912.	125.
840.0	4.886	.004	65539.	125.
845.0	4.907	.004	66166.	66.
850.0	4.928	.003	66497.	131.
855.0	4.945	.004	67153.	139.
860.0	4.967	.004	67847.	139.
865.0	4.989	.004	68541.	139.
870.0	5.012	.004	69234.	139.
875.0	5.034	.004	69928.	139.
880.0	5.056	.005	70622.	150.
885.0	5.080	.005	71370.	157.
890.0	5.103	.005	72155.	157.
895.0	5.127	.004	72940.	73.
900.0	5.145	.005	73305.	162.
905.0	5.170	.005	74115.	162.
910.0	5.196	.005	74926.	162.
915.0	5.222	.005	75738.	200.
920.0	5.247	.005	76737.	159.
925.0	5.273	.005	77533.	159.
930.0	5.299	.005	78329.	159.
935.0	5.325	.007	79125.	287.
940.0	5.361	.005	80558.	133.
945.0	5.386	.005	81222.	133.
950.0	5.411	.005	81886.	133.
955.0	5.436	.009	82550.	133.
960.0	5.482	.003	83214.	179.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 2*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
965.0	5.499	.003	84108.	84.
970.0	5.517	.003	84529.	85.
975.0	5.534	****	84951.	85.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 2*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
40.0	4.810	.001	63069.	63.
45.0	4.817	.001	63384.	63.
50.0	4.825	.001	63701.	64.
55.0	4.832	.001	64019.	64.
60.0	4.840	.001	64340.	64.
65.0	4.847	.001	64661.	65.
70.0	4.854	.001	64985.	65.
75.0	4.862	.001	65309.	65.
80.0	4.869	.001	65636.	66.
85.0	4.877	.001	65964.	66.
90.0	4.884	.001	66294.	66.
95.0	4.892	.001	66625.	67.
100.0	4.899	.001	66959.	67.
105.0	4.907	.001	67293.	67.
110.0	4.914	.001	67630.	68.
115.0	4.922	.000	67968.	68.
120.0	4.924	.002	68308.	68.
125.0	4.931	.002	68649.	69.
130.0	4.939	.002	68992.	69.
135.0	4.947	.002	69337.	69.
140.0	4.955	.002	69684.	70.
145.0	4.963	.002	70032.	70.
150.0	4.971	.002	70382.	70.
155.0	4.979	.002	70734.	71.
160.0	4.986	.002	71088.	71.
165.0	4.994	.002	71443.	71.
170.0	5.002	.002	71801.	72.
175.0	5.010	.002	72160.	72.
180.0	5.018	.002	72520.	73.
185.0	5.026	.000	72883.	73.
190.0	5.028	.002	73247.	73.
195.0	5.036	.002	73613.	74.
200.0	5.045	.002	73981.	74.
205.0	5.053	.002	74351.	74.
210.0	5.061	.002	74723.	75.
215.0	5.070	.002	75097.	75.
220.0	5.078	.002	75472.	75.
225.0	5.086	.002	75849.	76.
230.0	5.095	.002	76229.	76.
235.0	5.103	.002	76610.	77.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 2*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
240.0	5.112	.002	76993.	77.
245.0	5.120	.002	77378.	77.
250.0	5.128	.001	77765.	78.
255.0	5.131	.002	78153.	78.
260.0	5.140	.002	78544.	79.
265.0	5.149	.002	78937.	79.
270.0	5.158	.002	79331.	79.
275.0	5.167	.002	79728.	80.
280.0	5.176	.002	80127.	80.
285.0	5.184	.002	80527.	81.
290.0	5.193	.002	80930.	81.
295.0	5.202	.002	81335.	81.
300.0	5.211	.002	81741.	82.
305.0	5.220	****	82150.	82.
310.0	5.217	.002	82561.	83.
315.0	5.227	.002	82973.	83.
320.0	5.236	.002	83388.	83.
325.0	5.246	.002	83805.	84.
330.0	5.256	.002	84224.	84.
335.0	5.265	.002	84645.	85.
340.0	5.275	.002	85068.	85.
345.0	5.285	.002	85494.	85.
350.0	5.294	.002	85921.	86.
355.0	5.304	.002	86351.	86.
360.0	5.314	.002	86782.	87.
365.0	5.323	.001	87216.	87.
370.0	5.327	.002	87652.	88.
375.0	5.337	.002	88091.	88.
380.0	5.347	.002	88531.	89.
385.0	5.358	.002	88974.	89.
390.0	5.368	.002	89418.	89.
395.0	5.378	.002	89865.	90.
400.0	5.388	.002	90315.	90.
405.0	5.399	.002	90766.	91.
410.0	5.409	.002	91220.	91.
415.0	5.419	.002	91676.	92.
420.0	5.429	.001	92135.	92.
425.0	5.436	.002	92595.	93.
430.0	5.447	.002	93058.	93.
435.0	5.458	.002	93523.	94.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 2*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
440.0	5.469	.002	93991.	94.
445.0	5.480	.002	94461.	94.
450.0	5.491	.002	94933.	95.
455.0	5.501	.002	95408.	95.
460.0	5.512	.002	95885.	96.
465.0	5.523	.000	96364.	96.
470.0	5.524	.002	96846.	97.
475.0	5.536	.002	97330.	97.
480.0	5.548	.002	97817.	98.
485.0	5.559	.002	98306.	98.
490.0	5.571	.002	98797.	99.
495.0	5.583	.002	99291.	99.
500.0	5.595	.002	99788.	100.
505.0	5.606	.002	100287.	100.
510.0	5.618	.002	100788.	101.
515.0	5.630	.002	101292.	101.
520.0	5.639	.002	101798.	102.
525.0	5.651	.002	102307.	102.
530.0	5.664	.002	102819.	103.
535.0	5.676	.002	103333.	103.
540.0	5.689	.002	103850.	104.
545.0	5.701	.002	104369.	104.
550.0	5.713	.002	104891.	105.
555.0	5.726	.001	105415.	105.
560.0	5.729	.003	105942.	106.
565.0	5.743	.003	106472.	106.
570.0	5.756	.003	107004.	107.
575.0	5.769	.003	107539.	108.
580.0	5.783	.003	108077.	108.
585.0	5.796	.003	108617.	109.
590.0	5.809	.003	109160.	109.
595.0	5.823	.001	109706.	110.
600.0	5.830	.003	110254.	110.
605.0	5.844	.003	110806.	111.
610.0	5.858	.003	111360.	111.
615.0	5.872	.003	111916.	112.
620.0	5.887	.003	112476.	112.
625.0	5.901	.003	113038.	113.
630.0	5.915	.003	113604.	114.
635.0	5.929	.002	114172.	114.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 2*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
640.0	5.941	.003	114742.	115.
645.0	5.956	.003	115316.	115.
650.0	5.971	.003	115893.	116.
655.0	5.986	.003	116472.	116.
660.0	6.000	.003	117054.	117.
665.0	6.015	.003	117640.	118.
670.0	6.030	.003	118228.	118.
675.0	6.044	.003	118819.	119.
680.0	6.060	.003	119413.	119.
685.0	6.075	.003	120010.	120.
690.0	6.091	.003	120610.	121.
695.0	6.106	.003	121213.	121.
700.0	6.122	.001	121819.	155.
705.0	6.129	.003	122596.	162.
710.0	6.145	.003	123403.	123.
715.0	6.162	.003	124020.	124.
720.0	6.179	.003	124640.	125.
725.0	6.196	.003	125263.	125.
730.0	6.212	.003	125890.	126.
735.0	6.229	.003	126519.	127.
740.0	6.244	.004	127152.	127.
745.0	6.262	.004	127788.	128.
750.0	6.279	.004	128426.	128.
755.0	6.297	.004	129069.	129.
760.0	6.315	.004	129714.	130.
765.0	6.333	.003	130362.	130.
770.0	6.348	.004	131014.	131.
775.0	6.367	.004	131669.	132.
780.0	6.386	.004	132328.	132.
785.0	6.405	.004	132989.	133.
790.0	6.424	.002	133654.	134.
795.0	6.433	.004	134322.	134.
800.0	6.454	.004	134994.	135.
805.0	6.474	.004	135669.	136.
810.0	6.495	.004	136347.	136.
815.0	6.516	.004	137029.	137.
820.0	6.537	.005	137714.	138.
825.0	6.560	.004	138403.	138.
830.0	6.582	.004	139095.	139.
835.0	6.603	.004	139790.	140.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 2*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
840.0	6.625	.003	140489.	140.
845.0	6.639	.005	141191.	141.
850.0	6.662	.005	141897.	142.
855.0	6.685	.005	142607.	143.
860.0	6.709	.005	143320.	143.
865.0	6.732	.005	144036.	144.
870.0	6.758	.005	144756.	145.
875.0	6.782	.005	145480.	145.
880.0	6.807	.005	146208.	146.
885.0	6.831	.004	146939.	147.
890.0	6.853	.005	147673.	148.
895.0	6.879	.005	148412.	148.
900.0	6.905	.005	149154.	149.
905.0	6.932	.005	149899.	150.
910.0	6.956	.006	150649.	151.
915.0	6.984	.006	151402.	151.
920.0	7.012	.006	152159.	152.
925.0	7.040	.007	152920.	153.
930.0	7.077	.005	153684.	154.
935.0	7.104	.005	154453.	154.
940.0	7.132	.007	155225.	155.
945.0	7.166	.005	156001.	156.
950.0	7.193	.005	156781.	157.
955.0	7.220	.005	157565.	158.
960.0	7.246	.010	158353.	158.
965.0	7.296	.003	159144.	159.
970.0	7.311	.003	159940.	238.
975.0	7.326	****	161132.	161.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 1*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
550.0	4.497	.003	12307.	13.
555.0	4.514	.003	12370.	13.
560.0	4.530	.003	12434.	13.
565.0	4.547	.003	12497.	13.
570.0	4.563	.003	12561.	13.
575.0	4.580	.003	12625.	13.
580.0	4.596	.003	12688.	13.
585.0	4.613	.005	12752.	13.
590.0	4.636	.003	12816.	13.
595.0	4.652	.003	12880.	13.
600.0	4.669	.003	12944.	13.
605.0	4.686	.003	13009.	13.
610.0	4.702	.003	13074.	13.
615.0	4.719	.004	13139.	13.
620.0	4.738	.003	13205.	13.
625.0	4.755	.003	13271.	13.
630.0	4.772	.003	13337.	13.
635.0	4.790	.003	13404.	13.
640.0	4.807	.001	13471.	13.
645.0	4.813	.004	13539.	14.
650.0	4.832	.004	13606.	14.
655.0	4.851	.004	13674.	22.
660.0	4.870	.004	13784.	23.
665.0	4.889	.004	13901.	23.
670.0	4.908	.003	14018.	38.
675.0	4.922	.004	14210.	21.
680.0	4.942	.004	14314.	21.
685.0	4.962	.004	14419.	21.
690.0	4.982	.004	14524.	21.
695.0	5.002	.004	14628.	21.
700.0	5.022	.005	14733.	21.
705.0	5.048	.004	14838.	23.
710.0	5.068	.004	14955.	25.
715.0	5.089	.004	15079.	25.
720.0	5.110	.003	15203.	15.
725.0	5.123	.004	15279.	15.
730.0	5.145	.004	15356.	15.
735.0	5.168	.004	15433.	23.
740.0	5.190	.004	15550.	35.
745.0	5.212	.004	15726.	35.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 1*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
750.0	5.235	.005	15903.	16.
755.0	5.258	.005	15982.	29.
760.0	5.282	.005	16130.	30.
765.0	5.305	.003	16281.	38.
770.0	5.318	.005	16473.	38.
775.0	5.344	.005	16664.	38.
780.0	5.370	.005	16856.	38.
785.0	5.396	.005	17048.	38.
790.0	5.422	.006	17239.	68.
795.0	5.452	.005	17579.	38.
800.0	5.479	.005	17771.	38.
805.0	5.506	.004	17964.	38.
810.0	5.524	.006	18156.	38.
815.0	5.552	.006	18348.	53.
820.0	5.581	.006	18615.	40.
825.0	5.610	.005	18815.	19.
830.0	5.633	.006	18909.	33.
835.0	5.664	.006	19074.	44.
840.0	5.694	.006	19295.	44.
845.0	5.725	.006	19516.	44.
850.0	5.756	.006	19737.	44.
855.0	5.787	.006	19958.	44.
860.0	5.818	.005	20178.	44.
865.0	5.844	.007	20396.	44.
870.0	5.878	.007	20615.	44.
875.0	5.912	.007	20834.	44.
880.0	5.946	.007	21053.	71.
885.0	5.981	.007	21408.	44.
890.0	6.016	.009	21628.	44.
895.0	6.060	.007	21848.	53.
900.0	6.095	.007	22111.	32.
905.0	6.130	.010	22272.	46.
910.0	6.181	.007	22501.	46.
915.0	6.216	.006	22730.	75.
920.0	6.247	.007	23106.	40.
925.0	6.284	.007	23306.	40.
930.0	6.321	.008	23507.	40.
935.0	6.363	.008	23707.	65.
940.0	6.402	.008	24033.	24.
945.0	6.441	.010	24154.	30.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 1*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
950.0	6.492	.008	24302.	53.
955.0	6.533	.009	24568.	31.
960.0	6.577	.009	24722.	69.
965.0	6.621	.009	25065.	48.
970.0	6.667	.009	25306.	76.
975.0	6.712	.011	25688.	95.
980.0	6.769	.008	26160.	72.
985.0	6.811	.012	26522.	107.
990.0	6.873	.006	27059.	51.
995.0	6.902	.006	27311.	51.
1000.0	6.931	****	27564.	28.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
******	6.588	.002	24557.	25.
******	6.600	.002	24680.	25.
******	6.612	.002	24803.	25.
******	6.624	.002	24927.	25.
******	6.635	.002	25052.	25.
60.0	6.647	.002	25177.	25.
65.0	6.659	.002	25303.	25.
70.0	6.671	.002	25430.	25.
75.0	6.682	.002	25557.	26.
80.0	6.694	.002	25685.	26.
85.0	6.706	.002	25813.	26.
90.0	6.718	.002	25942.	26.
95.0	6.730	.002	26072.	26.
100.0	6.742	.002	26202.	26.
105.0	6.754	.002	26333.	26.
110.0	6.766	.002	26465.	26.
115.0	6.778	.002	26597.	27.
120.0	6.790	.002	26730.	27.
125.0	6.802	.002	26864.	27.
130.0	6.814	.002	26998.	27.
135.0	6.826	.002	27133.	27.
140.0	6.838	.002	27269.	27.
145.0	6.851	.002	27405.	27.
150.0	6.863	.002	27542.	28.
155.0	6.876	.002	27680.	28.
160.0	6.888	.002	27818.	28.
165.0	6.900	.002	27957.	28.
170.0	6.913	.002	28097.	28.
175.0	6.922	.003	28238.	28.
180.0	6.935	.003	28379.	28.
185.0	6.948	.003	28521.	29.
190.0	6.961	.003	28663.	29.
195.0	6.974	.003	28807.	29.
200.0	6.987	.003	28951.	29.
205.0	7.000	.003	29095.	29.
210.0	7.013	.002	29241.	29.
215.0	7.026	.003	29387.	29.
220.0	7.039	.003	29534.	30.
225.0	7.053	.003	29682.	30.
230.0	7.066	.003	29830.	30.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
235.0	7.080	.003	29979.	30.
240.0	7.093	.003	30129.	30.
245.0	7.107	.002	30280.	30.
250.0	7.115	.003	30431.	30.
255.0	7.129	.003	30583.	31.
260.0	7.143	.003	30736.	31.
265.0	7.158	.003	30890.	31.
270.0	7.172	.003	31044.	31.
275.0	7.186	.003	31200.	31.
280.0	7.200	.003	31356.	31.
285.0	7.214	.003	31512.	32.
290.0	7.230	.003	31670.	32.
295.0	7.244	.003	31828.	32.
300.0	7.259	.003	31987.	32.
305.0	7.274	.003	32147.	32.
310.0	7.288	.003	32308.	32.
315.0	7.303	.003	32470.	32.
320.0	7.317	.003	32632.	33.
325.0	7.332	.003	32795.	33.
330.0	7.347	.003	32959.	33.
335.0	7.362	.003	33124.	33.
340.0	7.377	.003	33289.	33.
345.0	7.392	.003	33456.	33.
350.0	7.408	.001	33623.	34.
355.0	7.415	.003	33791.	34.
360.0	7.431	.003	33960.	34.
365.0	7.447	.003	34130.	34.
370.0	7.463	.003	34301.	34.
375.0	7.479	.003	34472.	34.
380.0	7.495	.003	34645.	35.
385.0	7.511	.003	34818.	35.
390.0	7.528	.003	34992.	35.
395.0	7.545	.003	35167.	35.
400.0	7.561	.003	35343.	35.
405.0	7.578	.003	35519.	36.
410.0	7.594	.003	35697.	36.
415.0	7.611	.003	35875.	36.
420.0	7.625	.003	36055.	36.
425.0	7.643	.003	36235.	36.
430.0	7.660	.003	36416.	36.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
435.0	7.677	.003	36598.	37.
440.0	7.695	.003	36781.	37.
445.0	7.712	.004	36965.	37.
450.0	7.730	.004	37150.	37.
455.0	7.748	.004	37336.	37.
460.0	7.766	.004	37523.	38.
465.0	7.784	.004	37710.	38.
470.0	7.802	.004	37899.	38.
475.0	7.820	.004	38088.	38.
480.0	7.841	.004	38279.	38.
485.0	7.860	.004	38470.	38.
490.0	7.878	.004	38662.	39.
495.0	7.897	.004	38856.	39.
500.0	7.915	.003	39050.	39.
505.0	7.932	.004	39245.	39.
510.0	7.952	.004	39441.	39.
515.0	7.971	.004	39639.	40.
520.0	7.990	.004	39837.	40.
525.0	8.010	.003	40036.	40.
530.0	8.025	.004	40236.	40.
535.0	8.046	.004	40437.	40.
540.0	8.066	.004	40640.	41.
545.0	8.087	.004	40843.	41.
550.0	8.107	.003	41047.	41.
555.0	8.124	.004	41252.	41.
560.0	8.146	.004	41458.	41.
565.0	8.167	.004	41666.	42.
570.0	8.189	.004	41874.	42.
575.0	8.211	.004	42083.	42.
580.0	8.233	.004	42294.	42.
585.0	8.256	.004	42505.	43.
590.0	8.278	.004	42718.	43.
595.0	8.300	.004	42931.	43.
600.0	8.323	.006	43146.	43.
605.0	8.351	.005	43362.	43.
610.0	8.374	.005	43579.	44.
615.0	8.396	.005	43796.	44.
620.0	8.419	.005	44015.	62.
625.0	8.444	.005	44324.	120.
630.0	8.468	.005	44922.	120.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
635.0	8.491	.005	45519.	120.
640.0	8.515	.005	46117.	120.
645.0	8.540	.005	46714.	341.
650.0	8.564	.005	48420.	76.
655.0	8.589	.005	48801.	76.
660.0	8.613	.005	49182.	76.
665.0	8.637	.005	49564.	76.
670.0	8.662	.005	49945.	76.
675.0	8.688	.005	50327.	177.
680.0	8.713	.005	51213.	51.
685.0	8.740	.005	51469.	51.
690.0	8.766	.005	51727.	61.
695.0	8.793	.005	52033.	77.
700.0	8.819	.006	52417.	77.
705.0	8.848	.005	52801.	59.
710.0	8.875	.005	53096.	53.
715.0	8.902	.005	53361.	53.
720.0	8.929	.007	53628.	79.
725.0	8.963	.006	54024.	93.
730.0	8.991	.006	54489.	93.
735.0	9.019	.005	54953.	93.
740.0	9.046	.006	55418.	168.
745.0	9.076	.006	56259.	86.
750.0	9.105	.005	56690.	86.
755.0	9.130	.006	57122.	97.
760.0	9.161	.006	57608.	88.
765.0	9.193	.006	58049.	72.
770.0	9.224	.009	58406.	95.
775.0	9.267	.006	58880.	95.
780.0	9.298	.006	59354.	95.
785.0	9.329	.008	59828.	146.
790.0	9.368	.006	60561.	84.
795.0	9.400	.006	60981.	84.
800.0	9.432	.008	61400.	118.
805.0	9.472	.007	61990.	83.
810.0	9.505	.005	62405.	63.
815.0	9.528	.007	62722.	94.
820.0	9.565	.007	63192.	94.
825.0	9.602	.007	63661.	94.
830.0	9.639	.011	64130.	64.

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BISON_STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
835.0	9.692	.007	64451.	90.
840.0	9.728	.008	64899.	85.
845.0	9.766	.008	65325.	165.
850.0	9.806	.017	66150.	211.
855.0	9.893	.003	67203.	68.
860.0	9.908	.002	67545.	68.
865.0	9.917	.005	67888.	142.
870.0	9.941	.005	68598.	73.
875.0	9.965	.005	68961.	73.
880.0	9.989	.005	69325.	73.
885.0	10.013	****	69689.	73.
890.0	9.974	.009	70052.	73.
895.0	10.019	.009	70416.	73.
900.0	10.065	.009	70780.	73.
905.0	10.110	.568	71143.	73.
910.0	12.952	****	71507.	72.
915.0	10.233	.025	71864.	1137.
920.0	10.359	.029	77551.	78.
925.0	10.506	.010	77939.	78.
930.0	10.557	.009	78329.	78.
935.0	10.601	.009	78720.	341.
940.0	10.647	.011	80426.	232.
945.0	10.702	.010	81588.	106.
950.0	10.751	.013	82116.	348.
955.0	10.816	.010	83855.	258.
960.0	10.867	.009	85144.	258.
965.0	10.912	.013	86433.	86.
970.0	10.978	.006	86866.	87.
975.0	11.008	****	87300.	87.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
5.0	9.494	.003	62140.	62.
10.0	9.508	.003	62450.	62.
15.0	9.521	.003	62763.	63.
20.0	9.535	.003	63076.	63.
25.0	9.548	.003	63392.	63.
30.0	9.562	.003	63709.	64.
35.0	9.575	.003	64027.	64.
40.0	9.589	.003	64347.	64.
45.0	9.603	.003	64669.	65.
50.0	9.616	.004	64992.	65.
55.0	9.636	.003	65317.	65.
60.0	9.649	.003	65644.	66.
65.0	9.663	.003	65972.	66.
70.0	9.677	.003	66302.	66.
75.0	9.690	.003	66633.	67.
80.0	9.704	.003	66967.	67.
85.0	9.717	.003	67301.	67.
90.0	9.731	.003	67638.	68.
95.0	9.745	.003	67976.	68.
100.0	9.759	.003	68316.	68.
105.0	9.773	.003	68658.	69.
110.0	9.787	.003	69001.	69.
115.0	9.800	.003	69346.	69.
120.0	9.814	.003	69692.	70.
125.0	9.828	.003	70041.	70.
130.0	9.843	.003	70391.	70.
135.0	9.857	.003	70743.	71.
140.0	9.871	.003	71097.	71.
145.0	9.886	.003	71452.	71.
150.0	9.900	.003	71809.	72.
155.0	9.914	.004	72168.	72.
160.0	9.933	.003	72529.	73.
165.0	9.947	.003	72892.	73.
170.0	9.962	.003	73256.	73.
175.0	9.976	.003	73623.	74.
180.0	9.991	.003	73991.	74.
185.0	10.005	.002	74361.	74.
190.0	10.014	.003	74732.	75.
195.0	10.029	.003	75106.	75.
200.0	10.044	.003	75481.	75.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
205.0	10.060	.003	75859.	76.
210.0	10.075	.003	76238.	76.
215.0	10.090	.003	76619.	77.
220.0	10.105	.002	77002.	77.
225.0	10.118	.003	77387.	77.
230.0	10.134	.003	77774.	78.
235.0	10.150	.003	78163.	78.
240.0	10.166	.003	78554.	79.
245.0	10.182	.003	78947.	79.
250.0	10.198	.003	79341.	79.
255.0	10.213	.004	79738.	80.
260.0	10.233	.003	80137.	80.
265.0	10.249	.003	80537.	81.
270.0	10.265	.003	80940.	81.
275.0	10.281	.003	81345.	81.
280.0	10.297	.003	81751.	82.
285.0	10.313	.004	82160.	82.
290.0	10.331	.003	82571.	83.
295.0	10.348	.003	82984.	83.
300.0	10.364	.003	83398.	83.
305.0	10.380	.003	83815.	84.
310.0	10.397	.003	84234.	84.
315.0	10.413	.003	84656.	85.
320.0	10.429	.003	85079.	85.
325.0	10.446	.003	85504.	86.
330.0	10.463	.003	85932.	86.
335.0	10.480	.003	86361.	86.
340.0	10.497	.003	86793.	87.
345.0	10.514	.004	87227.	87.
350.0	10.534	.003	87663.	88.
355.0	10.551	.003	88101.	88.
360.0	10.568	.003	88542.	89.
365.0	10.585	.003	88985.	89.
370.0	10.603	.003	89429.	89.
375.0	10.620	.004	89877.	90.
380.0	10.639	.004	90326.	90.
385.0	10.657	.004	90778.	91.
390.0	10.675	.004	91231.	91.
395.0	10.693	.004	91688.	92.
400.0	10.711	.003	92146.	92.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 2*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 1**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
405.0	10.724	.004	92607.	93.
410.0	10.743	.004	93070.	93.
415.0	10.762	.004	93535.	94.
420.0	10.781	.004	94003.	94.
425.0	10.801	.004	94473.	94.
430.0	10.820	.004	94945.	95.
435.0	10.841	.004	95420.	95.
440.0	10.861	.004	95897.	96.
445.0	10.881	.004	96376.	96.
450.0	10.901	.004	96858.	97.
455.0	10.921	.004	97342.	97.
460.0	10.940	.004	97829.	98.
465.0	10.961	.004	98318.	98.
470.0	10.981	.004	98810.	99.
475.0	11.002	.004	99304.	99.
480.0	11.022	.005	99800.	100.
485.0	11.048	.004	100299.	100.
490.0	11.069	.004	100801.	101.
495.0	11.090	.004	101305.	101.
500.0	11.111	.004	101811.	102.
505.0	11.129	.004	102320.	102.
510.0	11.151	.004	102832.	103.
515.0	11.173	.004	103346.	103.
520.0	11.195	.004	103862.	104.
525.0	11.217	.006	104382.	104.
530.0	11.249	.004	104904.	105.
535.0	11.270	.004	105428.	105.
540.0	11.291	.004	105955.	106.
545.0	11.312	.005	106485.	106.
550.0	11.338	.004	107017.	107.
555.0	11.359	.004	107552.	108.
560.0	11.380	.004	108090.	108.
565.0	11.402	.004	108631.	109.
570.0	11.423	.008	109174.	109.
575.0	11.464	.003	109720.	110.
580.0	11.479	.003	110268.	110.
585.0	11.495	.003	110819.	111.
590.0	11.510	****	111373.	111.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES

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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
70.0	3.402	.001	24960.	25.
75.0	3.409	.001	25085.	25.
80.0	3.416	.001	25211.	25.
85.0	3.423	.001	25337.	25.
90.0	3.430	.001	25463.	25.
95.0	3.437	.001	25591.	26.
100.0	3.444	.001	25719.	26.
105.0	3.450	.001	25847.	26.
110.0	3.457	.001	25976.	26.
115.0	3.464	.001	26106.	26.
120.0	3.471	.001	26237.	26.
125.0	3.478	.001	26368.	26.
130.0	3.485	.001	26500.	26.
135.0	3.492	.001	26632.	27.
140.0	3.499	.001	26765.	27.
145.0	3.506	.001	26899.	27.
150.0	3.513	.001	27034.	27.
155.0	3.519	.001	27169.	27.
160.0	3.526	****	27305.	27.
165.0	3.524	.001	27441.	27.
170.0	3.532	.001	27578.	28.
175.0	3.539	.001	27716.	28.
180.0	3.546	.001	27855.	28.
185.0	3.554	.001	27994.	28.
190.0	3.561	.001	28134.	28.
195.0	3.569	.001	28275.	28.
200.0	3.576	.001	28416.	28.
205.0	3.583	.001	28558.	29.
210.0	3.591	.001	28701.	29.
215.0	3.598	.001	28845.	29.
220.0	3.606	.001	28989.	29.
225.0	3.613	.001	29134.	29.
230.0	3.620	****	29279.	29.
235.0	3.620	.002	29426.	29.
240.0	3.628	.002	29573.	30.
245.0	3.636	.002	29721.	30.
250.0	3.644	.002	29869.	30.
255.0	3.652	.002	30019.	30.
260.0	3.660	.002	30169.	30.
265.0	3.668	.002	30320.	30.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
270.0	3.676	.002	30471.	30.
275.0	3.684	.002	30624.	31.
280.0	3.691	.002	30777.	31.
285.0	3.699	.002	30931.	31.
290.0	3.707	.002	31085.	31.
295.0	3.715	.002	31241.	31.
300.0	3.723	****	31397.	31.
305.0	3.722	.002	31554.	32.
310.0	3.731	.002	31712.	32.
315.0	3.739	.002	31870.	32.
320.0	3.748	.002	32030.	32.
325.0	3.756	.002	32190.	32.
330.0	3.765	.002	32351.	32.
335.0	3.774	.002	32512.	33.
340.0	3.782	.002	32675.	33.
345.0	3.791	.002	32838.	33.
350.0	3.799	.002	33003.	33.
355.0	3.808	.002	33168.	33.
360.0	3.816	.002	33333.	33.
365.0	3.825	.000	33500.	34.
370.0	3.825	.002	33668.	34.
375.0	3.835	.002	33836.	34.
380.0	3.844	.002	34005.	34.
385.0	3.853	.002	34175.	34.
390.0	3.862	.002	34346.	34.
395.0	3.871	.002	34518.	35.
400.0	3.881	.002	34690.	35.
405.0	3.890	.002	34864.	35.
410.0	3.899	.002	35038.	35.
415.0	3.908	.002	35213.	35.
420.0	3.918	.002	35389.	35.
425.0	3.927	.000	35566.	36.
430.0	3.929	.002	35744.	36.
435.0	3.939	.002	35923.	36.
440.0	3.949	.002	36102.	36.
445.0	3.958	.002	36283.	36.
450.0	3.968	.002	36464.	36.
455.0	3.978	.002	36647.	37.
460.0	3.988	.002	36830.	37.
465.0	3.998	.002	37014.	37.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
470.0	4.008	.002	37199.	37.
475.0	4.018	.002	37385.	37.
480.0	4.028	.001	37572.	38.
485.0	4.032	.002	37760.	38.
490.0	4.042	.002	37949.	38.
495.0	4.053	.002	38138.	38.
500.0	4.064	.002	38329.	38.
505.0	4.074	.002	38521.	39.
510.0	4.085	.002	38713.	39.
515.0	4.095	.002	38907.	39.
520.0	4.106	.002	39101.	39.
525.0	4.116	.002	39297.	39.
530.0	4.127	.000	39493.	39.
535.0	4.129	.002	39691.	40.
540.0	4.141	.002	39889.	40.
545.0	4.152	.002	40089.	40.
550.0	4.164	.002	40289.	40.
555.0	4.175	.002	40491.	40.
560.0	4.187	.002	40693.	41.
565.0	4.198	.002	40897.	41.
570.0	4.210	.002	41101.	41.
575.0	4.221	****	41307.	41.
580.0	4.220	.003	41513.	42.
585.0	4.233	.003	41721.	42.
590.0	4.246	.003	41929.	42.
595.0	4.258	.003	42139.	42.
600.0	4.271	.003	42350.	42.
605.0	4.283	.003	42561.	43.
610.0	4.296	.003	42774.	43.
615.0	4.309	.003	42988.	43.
620.0	4.321	.001	43203.	43.
625.0	4.325	.003	43419.	43.
630.0	4.338	.003	43636.	44.
635.0	4.352	.003	43854.	44.
640.0	4.366	.003	44074.	44.
645.0	4.379	.003	44294.	44.
650.0	4.393	.003	44515.	45.
655.0	4.407	.003	44738.	45.
660.0	4.420	.001	44962.	45.
665.0	4.424	.003	45186.	45.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
670.0	4.439	.003	45412.	45.
675.0	4.454	.003	45639.	46.
680.0	4.469	.003	45868.	46.
685.0	4.484	.003	46097.	46.
690.0	4.498	.003	46327.	46.
695.0	4.513	.003	46559.	47.
700.0	4.528	.002	46792.	47.
705.0	4.540	.003	47026.	47.
710.0	4.556	.003	47261.	47.
715.0	4.571	.003	47497.	47.
720.0	4.587	.003	47735.	67.
725.0	4.603	.003	48071.	77.
730.0	4.619	.003	48456.	77.
735.0	4.634	.003	48840.	49.
740.0	4.648	.003	49085.	64.
745.0	4.665	.003	49404.	86.
750.0	4.682	.003	49833.	86.
755.0	4.698	.003	50261.	86.
760.0	4.715	.003	50690.	51.
765.0	4.732	.002	50944.	54.
770.0	4.744	.004	51214.	95.
775.0	4.762	.004	51687.	95.
780.0	4.780	.004	52161.	95.
785.0	4.798	.004	52635.	95.
790.0	4.816	.004	53108.	95.
795.0	4.834	.003	53582.	102.
800.0	4.850	.004	54093.	98.
805.0	4.869	.004	54582.	98.
810.0	4.888	.004	55071.	98.
815.0	4.907	.004	55560.	98.
820.0	4.927	.002	56049.	104.
825.0	4.939	.004	56571.	98.
830.0	4.960	.004	57061.	98.
835.0	4.980	.004	57551.	98.
840.0	5.001	.004	58041.	98.
845.0	5.022	.003	58532.	67.
850.0	5.037	.004	58866.	109.
855.0	5.059	.004	59412.	109.
860.0	5.081	.004	59958.	109.
865.0	5.104	.004	60505.	109.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 3*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
870.0	5.126	.004	61051.	93.
875.0	5.146	.005	61515.	114.
880.0	5.170	.005	62086.	114.
885.0	5.193	.005	62658.	114.
890.0	5.217	.005	63230.	114.
895.0	5.241	.006	63801.	91.
900.0	5.269	.005	64257.	129.
905.0	5.294	.005	64902.	129.
910.0	5.318	.005	65546.	66.
915.0	5.343	.005	65874.	130.
920.0	5.368	.005	66525.	146.
925.0	5.394	.005	67256.	146.
930.0	5.421	.003	67987.	146.
935.0	5.435	.006	68719.	69.
940.0	5.464	.006	69062.	69.
945.0	5.494	.006	69407.	134.
950.0	5.523	.006	70079.	300.
955.0	5.555	.006	71581.	72.
960.0	5.584	.006	71939.	300.
965.0	5.614	.006	73437.	368.
970.0	5.643	.010	75275.	105.
975.0	5.691	.005	75801.	481.
980.0	5.717	.005	78206.	567.
985.0	5.744	.009	81043.	424.
990.0	5.791	.003	83161.	424.
995.0	5.808	.003	85280.	424.
1000.0	5.825	****	87398.	87.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 3*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
******	4.911	.001	57396.	57.
******	4.918	.001	57683.	58.
******	4.926	.001	57971.	58.
******	4.933	.001	58261.	58.
25.0	4.940	.001	58552.	59.
30.0	4.947	.001	58845.	59.
35.0	4.955	.001	59139.	59.
40.0	4.962	.001	59435.	59.
45.0	4.969	.001	59732.	60.
50.0	4.977	.001	60031.	60.
55.0	4.984	.001	60331.	60.
60.0	4.991	.001	60633.	61.
65.0	4.999	.001	60936.	61.
70.0	5.006	.001	61241.	61.
75.0	5.013	.001	61547.	62.
80.0	5.021	.001	61854.	62.
85.0	5.024	.002	62164.	62.
90.0	5.031	.002	62475.	62.
95.0	5.039	.002	62787.	63.
100.0	5.047	.002	63101.	63.
105.0	5.054	.002	63416.	63.
110.0	5.062	.002	63733.	64.
115.0	5.070	.002	64052.	64.
120.0	5.077	.002	64372.	64.
125.0	5.085	.002	64694.	65.
130.0	5.093	.002	65018.	65.
135.0	5.100	.002	65343.	65.
140.0	5.108	.002	65670.	66.
145.0	5.116	.002	65998.	66.
150.0	5.123	.000	66328.	66.
155.0	5.124	.002	66659.	67.
160.0	5.133	.002	66993.	67.
165.0	5.141	.002	67328.	67.
170.0	5.149	.002	67664.	68.
175.0	5.157	.002	68003.	68.
180.0	5.165	.002	68343.	68.
185.0	5.173	.002	68684.	69.
190.0	5.181	.002	69028.	69.
195.0	5.189	.002	69373.	69.
200.0	5.198	.002	69720.	70.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
205.0	5.206	.002	70068.	70.
210.0	5.214	.002	70418.	70.
215.0	5.222	****	70770.	71.
220.0	5.221	.002	71124.	71.
225.0	5.230	.002	71480.	71.
230.0	5.239	.002	71837.	72.
235.0	5.248	.002	72196.	72.
240.0	5.256	.002	72557.	73.
245.0	5.265	.002	72920.	73.
250.0	5.274	.002	73285.	73.
255.0	5.282	.002	73651.	74.
260.0	5.291	.002	74019.	74.
265.0	5.300	.002	74389.	74.
270.0	5.309	.002	74761.	75.
275.0	5.317	.002	75135.	75.
280.0	5.326	.001	75511.	76.
285.0	5.329	.002	75888.	76.
290.0	5.338	.002	76268.	76.
295.0	5.347	.002	76649.	77.
300.0	5.357	.002	77032.	77.
305.0	5.366	.002	77417.	77.
310.0	5.375	.002	77804.	78.
315.0	5.385	.002	78193.	78.
320.0	5.394	.002	78584.	79.
325.0	5.403	.002	78977.	79.
330.0	5.412	.002	79372.	79.
335.0	5.422	****	79769.	80.
340.0	5.419	.002	80168.	80.
345.0	5.429	.002	80568.	81.
350.0	5.439	.002	80971.	81.
355.0	5.450	.002	81376.	81.
360.0	5.460	.002	81783.	82.
365.0	5.470	.002	82192.	82.
370.0	5.480	.002	82603.	83.
375.0	5.491	.002	83016.	83.
380.0	5.501	.002	83431.	83.
385.0	5.511	.002	83848.	84.
390.0	5.521	****	84267.	84.
395.0	5.520	.002	84688.	85.
400.0	5.531	.002	85112.	85.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
405.0	5.542	.002	85537.	86.
410.0	5.553	.002	85965.	86.
415.0	5.564	.002	86395.	86.
420.0	5.575	.002	86827.	87.
425.0	5.587	.002	87261.	87.
430.0	5.598	.002	87697.	88.
435.0	5.609	.002	88135.	88.
440.0	5.620	.002	88576.	89.
445.0	5.631	.002	89019.	89.
450.0	5.641	.002	89464.	89.
455.0	5.652	.002	89911.	90.
460.0	5.664	.002	90361.	90.
465.0	5.675	.002	90813.	91.
470.0	5.687	.002	91267.	91.
475.0	5.699	.002	91723.	92.
480.0	5.710	.002	92182.	92.
485.0	5.722	.001	92642.	93.
490.0	5.725	.002	93106.	93.
495.0	5.737	.002	93571.	94.
500.0	5.750	.002	94039.	94.
505.0	5.762	.002	94509.	95.
510.0	5.774	.002	94982.	95.
515.0	5.786	.002	95456.	95.
520.0	5.798	.002	95934.	96.
525.0	5.811	.002	96413.	96.
530.0	5.823	.003	96895.	97.
535.0	5.836	.003	97380.	97.
540.0	5.848	.003	97867.	98.
545.0	5.861	.003	98356.	98.
550.0	5.873	.003	98848.	99.
555.0	5.886	.003	99342.	99.
560.0	5.899	.003	99839.	100.
565.0	5.911	.003	100338.	100.
570.0	5.924	.001	100840.	101.
575.0	5.931	.003	101344.	101.
580.0	5.944	.003	101850.	102.
585.0	5.957	.003	102360.	102.
590.0	5.971	.003	102871.	103.
595.0	5.984	.003	103386.	103.
600.0	5.998	.003	103903.	104.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 3*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
605.0	6.011	.003	104422.	104.
610.0	6.025	.001	104944.	105.
615.0	6.032	.003	105469.	105.
620.0	6.046	.003	105996.	106.
625.0	6.060	.003	106526.	107.
630.0	6.075	.003	107059.	107.
635.0	6.089	.003	107594.	108.
640.0	6.103	.003	108132.	108.
645.0	6.118	.003	108673.	109.
650.0	6.132	.002	109216.	109.
655.0	6.140	.003	109762.	110.
660.0	6.156	.003	110311.	110.
665.0	6.172	.003	110862.	111.
670.0	6.187	.003	111416.	111.
675.0	6.203	.003	111973.	112.
680.0	6.219	.003	112533.	113.
685.0	6.234	.002	113096.	113.
690.0	6.244	.003	113661.	114.
695.0	6.260	.003	114230.	114.
700.0	6.277	.003	114801.	115.
705.0	6.294	.003	115375.	115.
710.0	6.311	.003	115952.	116.
715.0	6.328	.001	116531.	117.
720.0	6.335	.004	117114.	117.
725.0	6.353	.004	117699.	118.
730.0	6.371	.004	118288.	118.
735.0	6.389	.004	118879.	119.
740.0	6.407	.004	119474.	119.
745.0	6.425	.002	120071.	120.
750.0	6.434	.004	120671.	121.
755.0	6.454	.004	121275.	121.
760.0	6.473	.004	121881.	122.
765.0	6.492	.004	122490.	122.
770.0	6.511	.004	123103.	123.
775.0	6.531	.004	123718.	124.
780.0	6.550	.004	124337.	124.
785.0	6.569	.004	124958.	125.
790.0	6.588	.004	125583.	126.
795.0	6.608	.004	126211.	126.
800.0	6.627	.002	126842.	127.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
805.0	6.637	.004	127476.	127.
810.0	6.659	.004	128114.	128.
815.0	6.680	.004	128754.	129.
820.0	6.701	.004	129398.	129.
825.0	6.723	.003	130045.	130.
830.0	6.739	.005	130695.	131.
835.0	6.762	.005	131349.	131.
840.0	6.785	.005	132005.	132.
845.0	6.808	.005	132665.	133.
850.0	6.831	.004	133329.	133.
855.0	6.853	.005	133995.	134.
860.0	6.877	.005	134665.	135.
865.0	6.901	.005	135338.	135.
870.0	6.926	.004	136015.	136.
875.0	6.943	.005	136695.	137.
880.0	6.970	.005	137379.	137.
885.0	6.996	.005	138065.	138.
890.0	7.023	.005	138756.	139.
895.0	7.046	.006	139450.	139.
900.0	7.074	.006	140147.	140.
905.0	7.103	.006	140847.	141.
910.0	7.131	.007	141552.	142.
915.0	7.166	.006	142259.	142.
920.0	7.194	.006	142971.	143.
925.0	7.222	.006	143685.	144.
930.0	7.252	.006	144404.	144.
935.0	7.281	.006	145126.	145.
940.0	7.309	.006	145851.	146.
945.0	7.337	.010	146581.	147.
950.0	7.388	.004	147314.	147.
955.0	7.406	.004	148050.	148.
960.0	7.424	****	148790.	149.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 1*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
500.0	5.364	.111	18654.	1733.
505.0	5.918	.236	27319.	3277.
510.0	7.097	****	43704.	44.
515.0	-4.300	.058	43923.	44.
520.0	-4.011	.058	44142.	44.
525.0	-3.723	.058	44363.	44.
530.0	-3.434	.058	44585.	45.
535.0	-3.145	.058	44808.	45.
540.0	-2.856	.058	45032.	45.
545.0	-2.568	.058	45257.	45.
550.0	-2.279	.058	45483.	45.
555.0	-1.990	.058	45710.	46.
560.0	-1.701	.058	45939.	46.
565.0	-1.412	.058	46169.	46.
570.0	-1.124	.058	46400.	46.
575.0	-0.835	.058	46632.	47.
580.0	-0.546	.058	46865.	47.
585.0	-0.257	.058	47099.	47.
590.0	0.032	.058	47335.	47.
595.0	0.320	.058	47571.	48.
600.0	0.609	.058	47809.	48.
605.0	0.898	.058	48048.	48.
610.0	1.187	.058	48288.	48.
615.0	1.475	.058	48530.	49.
620.0	1.764	.058	48772.	49.
625.0	2.053	.058	49016.	49.
630.0	2.342	.058	49261.	49.
635.0	2.631	.058	49508.	50.
640.0	2.919	.058	49755.	50.
645.0	3.208	.058	50004.	50.
650.0	3.497	.058	50254.	50.
655.0	3.786	.058	50505.	51.
660.0	4.074	.058	50758.	51.
665.0	4.363	.058	51012.	51.
670.0	4.652	.058	51267.	51.
675.0	4.941	****	51523.	52.
680.0	4.875	.023	51781.	52.
685.0	4.991	.013	52039.	52.
690.0	5.056	****	52300.	52.
695.0	5.053	.004	52561.	53.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 1*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
700.0	5.072	.004	52824.	53.
705.0	5.091	.004	53088.	53.
710.0	5.110	****	53354.	53.
715.0	5.109	.004	53620.	54.
720.0	5.131	.004	53888.	54.
725.0	5.153	.004	54158.	54.
730.0	5.175	.004	54429.	54.
735.0	5.197	.004	54701.	55.
740.0	5.219	.005	54974.	55.
745.0	5.244	.005	55249.	55.
750.0	5.267	.005	55525.	56.
755.0	5.290	.005	55803.	56.
760.0	5.313	.004	56082.	56.
765.0	5.331	.005	56362.	56.
770.0	5.355	.005	56644.	57.
775.0	5.380	.005	56927.	57.
780.0	5.404	.005	57212.	57.
785.0	5.429	.006	57498.	57.
790.0	5.460	.005	57786.	58.
795.0	5.485	.005	58075.	58.
800.0	5.510	.003	58365.	58.
805.0	5.527	.005	58657.	59.
810.0	5.554	.005	58950.	59.
815.0	5.582	.005	59245.	59.
820.0	5.609	.005	59541.	60.
825.0	5.634	.006	59839.	60.
830.0	5.663	.006	60138.	60.
835.0	5.693	.006	60439.	60.
840.0	5.722	.007	60741.	61.
845.0	5.757	.006	61044.	61.
850.0	5.787	.006	61350.	61.
855.0	5.817	.006	61656.	62.
860.0	5.848	.006	61965.	62.
865.0	5.879	.006	62275.	62.
870.0	5.910	.006	62586.	63.
875.0	5.942	.007	62899.	63.
880.0	5.975	.007	63213.	63.
885.0	6.008	.007	63529.	64.
890.0	6.042	.007	63847.	64.
895.0	6.077	.007	64166.	64.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 1*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
900.0	6.112	.007	64487.	64.
905.0	6.148	.007	64810.	65.
910.0	6.185	.007	65134.	65.
915.0	6.221	.009	65459.	65.
920.0	6.264	.008	65787.	66.
925.0	6.302	.008	66115.	66.
930.0	6.340	.010	66446.	66.
935.0	6.391	.008	66778.	67.
940.0	6.430	.008	67112.	67.
945.0	6.469	.008	67448.	67.
950.0	6.510	.007	67785.	68.
955.0	6.547	.009	68124.	68.
960.0	6.592	.009	68464.	68.
965.0	6.637	.013	68806.	69.
970.0	6.701	.008	69150.	69.
975.0	6.742	.012	69496.	69.
980.0	6.802	.007	69844.	70.
985.0	6.839	.011	70193.	70.
990.0	6.894	.003	70544.	71.
995.0	6.909	****	70896.	71.

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BISON STRAIN GAGE INSTRUMENT

CALIBRATION TABLES

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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*4*INCHES

SENSOR PAIR NUMBER* 2**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
50.0	6.590	.002	25031.	25.
55.0	6.602	.002	25156.	25.
60.0	6.614	.002	25282.	25.
65.0	6.626	.002	25409.	25.
70.0	6.638	.002	25536.	26.
75.0	6.650	.002	25663.	26.
80.0	6.662	.002	25792.	26.
85.0	6.674	.002	25921.	26.
90.0	6.686	.002	26050.	26.
95.0	6.698	.002	26180.	26.
100.0	6.711	.003	26311.	26.
105.0	6.727	.002	26443.	26.
110.0	6.739	.002	26575.	27.
115.0	6.752	.002	26708.	27.
120.0	6.764	.002	26841.	27.
125.0	6.776	.002	26976.	27.
130.0	6.788	.002	27111.	27.
135.0	6.800	.002	27246.	27.
140.0	6.812	.002	27382.	27.
145.0	6.824	.002	27519.	28.
150.0	6.836	.002	27657.	28.
155.0	6.849	.002	27795.	28.
160.0	6.861	.002	27934.	28.
165.0	6.874	.002	28074.	28.
170.0	6.886	.002	28214.	28.
175.0	6.898	.002	28355.	28.
180.0	6.911	.002	28497.	28.
185.0	6.921	.003	28639.	29.
190.0	6.934	.003	28783.	29.
195.0	6.947	.003	28927.	29.
200.0	6.960	.003	29071.	29.
205.0	6.973	.003	29217.	29.
210.0	6.986	.003	29363.	29.
215.0	6.999	.003	29509.	30.
220.0	7.012	.002	29657.	30.
225.0	7.023	.003	29805.	30.
230.0	7.037	.003	29954.	30.
235.0	7.050	.003	30104.	30.
240.0	7.064	.003	30255.	30.
245.0	7.077	.003	30406.	30.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
250.0	7.091	.003	30558.	31.
255.0	7.104	.003	30711.	31.
260.0	7.118	.003	30864.	31.
265.0	7.133	.003	31019.	31.
270.0	7.147	.003	31174.	31.
275.0	7.161	.003	31330.	31.
280.0	7.175	.003	31486.	31.
285.0	7.189	.003	31644.	32.
290.0	7.202	.003	31802.	32.
295.0	7.216	.003	31961.	32.
300.0	7.229	.003	32121.	32.
305.0	7.244	.003	32281.	32.
310.0	7.258	.003	32443.	32.
315.0	7.273	.003	32605.	33.
320.0	7.287	.003	32768.	33.
325.0	7.302	.003	32932.	33.
330.0	7.316	.003	33096.	33.
335.0	7.329	.003	33262.	33.
340.0	7.344	.003	33428.	33.
345.0	7.359	.003	33595.	34.
350.0	7.374	.003	33763.	34.
355.0	7.390	.003	33932.	34.
360.0	7.405	.003	34102.	34.
365.0	7.420	.003	34272.	34.
370.0	7.435	.003	34444.	34.
375.0	7.451	.003	34616.	35.
380.0	7.467	.003	34789.	35.
385.0	7.483	.003	34963.	35.
390.0	7.499	.003	35138.	35.
395.0	7.515	.003	35313.	35.
400.0	7.528	.003	35490.	35.
405.0	7.545	.003	35667.	36.
410.0	7.561	.003	35846.	36.
415.0	7.578	.003	36025.	36.
420.0	7.595	.003	36205.	36.
425.0	7.611	.003	36386.	36.
430.0	7.624	.003	36568.	37.
435.0	7.641	.003	36751.	37.
440.0	7.659	.003	36935.	37.
445.0	7.676	.003	37119.	37.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 3*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
450.0	7.694	.003	37305.	37.
455.0	7.711	.003	37491.	37.
460.0	7.728	.004	37679.	38.
465.0	7.746	.004	37867.	38.
470.0	7.764	.004	38057.	38.
475.0	7.782	.004	38247.	38.
480.0	7.800	.004	38438.	38.
485.0	7.818	.004	38630.	39.
490.0	7.840	.004	38823.	39.
495.0	7.859	.004	39018.	39.
500.0	7.877	.004	39213.	39.
505.0	7.896	.004	39409.	39.
510.0	7.914	.003	39606.	40.
515.0	7.931	.004	39804.	40.
520.0	7.950	.004	40003.	40.
525.0	7.970	.004	40203.	40.
530.0	7.989	.004	40404.	40.
535.0	8.008	.003	40606.	41.
540.0	8.024	.004	40809.	41.
545.0	8.045	.004	41013.	41.
550.0	8.065	.004	41218.	41.
555.0	8.085	.004	41424.	41.
560.0	8.106	.004	41631.	42.
565.0	8.124	.004	41839.	42.
570.0	8.145	.004	42048.	42.
575.0	8.166	.004	42259.	42.
580.0	8.188	.004	42470.	42.
585.0	8.209	.004	42682.	43.
590.0	8.230	.004	42896.	43.
595.0	8.252	.004	43110.	43.
600.0	8.274	.004	43326.	43.
605.0	8.296	.004	43542.	44.
610.0	8.319	.005	43760.	44.
615.0	8.345	.005	43979.	44.
620.0	8.368	.005	44199.	44.
625.0	8.391	.005	44420.	44.
630.0	8.413	.004	44642.	45.
635.0	8.434	.005	44865.	45.
640.0	8.458	.005	45089.	45.
645.0	8.482	.005	45315.	45.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
650.0	8.506	.004	45541.	46.
655.0	8.526	.005	45769.	46.
660.0	8.551	.005	45998.	46.
665.0	8.577	.005	46228.	46.
670.0	8.602	.005	46459.	46.
675.0	8.627	.007	46691.	47.
680.0	8.663	.005	46925.	47.
685.0	8.688	.005	47159.	47.
690.0	8.713	.004	47395.	47.
695.0	8.734	.005	47632.	48.
700.0	8.760	.005	47870.	48.
705.0	8.787	.005	48110.	48.
710.0	8.813	.006	48350.	48.
715.0	8.842	.006	48592.	49.
720.0	8.869	.006	48835.	49.
725.0	8.897	.006	49079.	49.
730.0	8.925	.007	49325.	49.
735.0	8.959	.006	49571.	50.
740.0	8.987	.006	49819.	50.
745.0	9.016	.006	50068.	50.
750.0	9.046	.006	50318.	50.
755.0	9.075	.006	50570.	51.
760.0	9.103	.006	50823.	51.
765.0	9.132	.009	51077.	51.
770.0	9.175	.006	51332.	51.
775.0	9.203	.006	51589.	52.
780.0	9.231	.007	51847.	52.
785.0	9.267	.006	52106.	52.
790.0	9.296	.006	52367.	52.
795.0	9.325	.006	52629.	53.
800.0	9.354	.006	52892.	53.
805.0	9.385	.006	53156.	53.
810.0	9.416	.005	53422.	53.
815.0	9.439	.007	53689.	215.
820.0	9.473	.007	54763.	350.
825.0	9.507	.006	56513.	350.
830.0	9.539	.007	58262.	350.
835.0	9.575	.007	60012.	350.
840.0	9.612	.008	61761.	62.
845.0	9.653	.008	62070.	62.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
850.0	9.690	.008	62381.	62.
855.0	9.728	.011	62692.	63.
860.0	9.781	.007	63006.	63.
865.0	9.817	.008	63321.	63.
870.0	9.856	.007	63638.	64.
875.0	9.892	.007	63956.	64.
880.0	9.929	.010	64275.	64.
885.0	9.980	.007	64597.	277.
890.0	10.016	.007	65980.	259.
895.0	10.051	.008	67276.	259.
900.0	10.091	.008	68573.	259.
905.0	10.131	.009	69869.	259.
910.0	10.174	.009	71165.	259.
915.0	10.217	.009	72461.	259.
920.0	10.262	.009	73757.	265.
925.0	10.308	.009	75084.	75.
930.0	10.354	.010	75459.	75.
935.0	10.403	.010	75837.	76.
940.0	10.451	.015	76216.	76.
945.0	10.525	.010	76597.	119.
950.0	10.575	.008	77193.	206.
955.0	10.618	.012	78225.	303.
960.0	10.679	.006	79738.	119.
965.0	10.711	****	80332.	119.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
240.0	10.081	.003	71419.	71.
245.0	10.097	.003	71776.	72.
250.0	10.114	.003	72135.	72.
255.0	10.130	.003	72496.	72.
260.0	10.146	.003	72858.	73.
265.0	10.163	.003	73222.	73.
270.0	10.179	.003	73588.	74.
275.0	10.196	.003	73956.	74.
280.0	10.212	.005	74326.	74.
285.0	10.236	.003	74698.	75.
290.0	10.253	.003	75071.	75.
295.0	10.269	.003	75446.	75.
300.0	10.285	.003	75824.	76.
305.0	10.301	.003	76203.	76.
310.0	10.317	.004	76584.	77.
315.0	10.336	.003	76967.	77.
320.0	10.352	.003	77351.	77.
325.0	10.369	.003	77738.	78.
330.0	10.385	.003	78127.	78.
335.0	10.402	.003	78517.	79.
340.0	10.418	.004	78910.	79.
345.0	10.436	.003	79304.	79.
350.0	10.453	.003	79701.	80.
355.0	10.470	.003	80099.	80.
360.0	10.487	.003	80500.	80.
365.0	10.504	.003	80902.	81.
370.0	10.521	.004	81307.	81.
375.0	10.543	.003	81713.	82.
380.0	10.560	.003	82122.	82.
385.0	10.578	.003	82532.	83.
390.0	10.595	.003	82945.	83.
395.0	10.612	.003	83360.	83.
400.0	10.626	.004	83777.	84.
405.0	10.644	.004	84195.	84.
410.0	10.662	.004	84616.	85.
415.0	10.680	.004	85039.	85.
420.0	10.699	.004	85465.	85.
425.0	10.717	.005	85892.	86.
430.0	10.739	.004	86321.	86.
435.0	10.758	.004	86753.	87.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 3*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 2**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
440.0	10.776	.004	87187.	87.
445.0	10.795	.004	87623.	88.
450.0	10.813	.004	88061.	88.
455.0	10.835	.004	88501.	89.
460.0	10.853	.004	88943.	89.
465.0	10.871	.004	89388.	89.
470.0	10.890	.004	89835.	90.
475.0	10.908	.004	90284.	90.
480.0	10.929	.004	90735.	91.
485.0	10.947	.004	91189.	91.
490.0	10.966	.004	91645.	92.
495.0	10.984	.004	92103.	92.
500.0	11.003	.004	92564.	93.
505.0	11.021	.007	93027.	93.
510.0	11.058	.003	93492.	93.
515.0	11.072	.003	93959.	94.
520.0	11.087	.003	94429.	94.
525.0	11.101	.003	94901.	95.
530.0	11.115	****	95375.	95.

AD-A115 677 NEW MEXICO ENGINEERING RESEARCH INST ALBUQUERQUE F/G 13/2
INSTRUMENTATION FOR VERIFICATION OF BOMB DAMAGE REPAIR COMPUTER--ETC(U)
SEP 81 G T BAIRD F29601-76-C-0015
UNCLASSIFIED NMERI-TA5-1 AFESC/ESL-TR-81-51 NL

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
430.0	3.798	.002	34630.	60.
435.0	3.808	.002	34928.	60.
440.0	3.818	.002	35225.	60.
445.0	3.829	.002	35523.	60.
450.0	3.839	.002	35820.	60.
455.0	3.850	.002	36118.	60.
460.0	3.860	.002	36416.	60.
465.0	3.870	.002	36713.	60.
470.0	3.881	.002	37011.	60.
475.0	3.891	.002	37309.	60.
480.0	3.902	.002	37606.	38.
485.0	3.912	.002	37794.	38.
490.0	3.922	.001	37983.	38.
495.0	3.927	.002	38173.	38.
500.0	3.938	.002	38364.	38.
505.0	3.949	.002	38556.	39.
510.0	3.960	.002	38749.	39.
515.0	3.971	.002	38942.	65.
520.0	3.982	.002	39269.	70.
525.0	3.993	.002	39620.	70.
530.0	4.004	.002	39971.	70.
535.0	4.015	.002	40323.	70.
540.0	4.027	.001	40674.	41.
545.0	4.031	.002	40877.	41.
550.0	4.043	.002	41082.	69.
555.0	4.055	.002	41425.	75.
560.0	4.067	.002	41801.	75.
565.0	4.079	.002	42176.	75.
570.0	4.091	.002	42551.	75.
575.0	4.102	.002	42927.	43.
580.0	4.114	.002	43142.	61.
585.0	4.126	.001	43448.	78.
590.0	4.132	.003	43837.	78.
595.0	4.144	.003	44226.	78.
600.0	4.157	.003	44616.	78.
605.0	4.170	.003	45005.	78.
610.0	4.183	.003	45394.	78.
615.0	4.196	.003	45783.	78.
620.0	4.208	.003	46172.	78.
625.0	4.221	.001	46562.	78.

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BISON STRAIN GAGE INSTRUMENT

CALIBRATION TABLES

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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*2*INCHES

SENSOR PAIR NUMBER* 3**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
630.0	4.224	.003	46951.	78.
635.0	4.238	.003	47340.	78.
640.0	4.252	.003	47729.	168.
645.0	4.266	.003	48568.	76.
650.0	4.280	.003	48946.	76.
655.0	4.293	.003	49324.	76.
660.0	4.307	.003	49702.	76.
665.0	4.321	.001	50080.	50.
670.0	4.328	.003	50331.	50.
675.0	4.343	.003	50582.	79.
680.0	4.358	.003	50979.	82.
685.0	4.373	.003	51391.	82.
690.0	4.388	.003	51803.	82.
695.0	4.402	.003	52215.	82.
700.0	4.417	.003	52627.	53.
705.0	4.432	.003	52890.	82.
710.0	4.447	.003	53298.	86.
715.0	4.463	.003	53729.	86.
720.0	4.478	.003	54160.	86.
725.0	4.494	.003	54592.	86.
730.0	4.510	.003	55023.	86.
735.0	4.526	.001	55454.	55.
740.0	4.531	.003	55731.	70.
745.0	4.549	.003	56083.	99.
750.0	4.566	.003	56575.	99.
755.0	4.583	.003	57068.	99.
760.0	4.600	.003	57561.	99.
765.0	4.617	.003	58053.	99.
770.0	4.635	.003	58546.	72.
775.0	4.651	.004	58906.	104.
780.0	4.669	.004	59425.	104.
785.0	4.688	.004	59943.	104.
790.0	4.706	.004	60462.	104.
795.0	4.724	.002	60980.	61.
800.0	4.733	.004	61285.	64.
805.0	4.753	.004	61603.	120.
810.0	4.772	.004	62200.	120.
815.0	4.792	.004	62798.	120.
820.0	4.812	.004	63395.	63.
825.0	4.832	.004	63712.	79.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
830.0	4.851	.004	64108.	140.
835.0	4.872	.004	64810.	140.
840.0	4.893	.004	65512.	140.
845.0	4.914	.004	66214.	140.
850.0	4.936	.004	66916.	140.
855.0	4.955	.005	67618.	137.
860.0	4.978	.005	68303.	152.
865.0	5.000	.005	69065.	152.
870.0	5.023	.003	69827.	71.
875.0	5.036	.005	70181.	167.
880.0	5.060	.005	71016.	167.
885.0	5.085	.005	71851.	167.
890.0	5.110	.005	72686.	167.
895.0	5.135	.006	73521.	193.
900.0	5.162	.005	74485.	179.
905.0	5.188	.005	75379.	179.
910.0	5.214	.005	76273.	179.
915.0	5.240	.005	77167.	172.
920.0	5.267	.006	78026.	192.
925.0	5.295	.006	78984.	192.
930.0	5.323	.004	79942.	118.
935.0	5.341	.006	80531.	209.
940.0	5.371	.006	81579.	209.
945.0	5.402	.006	82626.	209.
950.0	5.432	.008	83673.	306.
955.0	5.473	.006	85203.	197.
960.0	5.502	.006	86188.	197.
965.0	5.531	.008	87173.	281.
970.0	5.572	.006	88576.	183.
975.0	5.599	.006	89492.	183.
980.0	5.627	.009	90409.	290.
985.0	5.670	.005	91859.	152.
990.0	5.693	.005	92618.	152.
995.0	5.716	.005	93376.	152.
1000.0	5.739	****	94134.	94.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
5.0	4.807	.001	63046.	63.
10.0	4.815	.001	63361.	63.
15.0	4.822	.001	63678.	64.
20.0	4.830	.001	63996.	64.
25.0	4.837	.001	64316.	64.
30.0	4.845	.001	64638.	65.
35.0	4.852	.001	64961.	65.
40.0	4.860	.001	65286.	65.
45.0	4.867	.001	65612.	66.
50.0	4.875	.001	65940.	66.
55.0	4.882	.001	66270.	66.
60.0	4.890	.001	66601.	67.
65.0	4.897	.001	66934.	67.
70.0	4.905	.001	67269.	67.
75.0	4.912	.001	67605.	68.
80.0	4.920	.001	67943.	68.
85.0	4.927	.001	68283.	68.
90.0	4.934	.002	68624.	69.
95.0	4.941	.002	68967.	69.
100.0	4.949	.002	69312.	69.
105.0	4.957	.002	69658.	70.
110.0	4.965	.002	70007.	70.
115.0	4.972	.002	70357.	70.
120.0	4.980	.002	70708.	71.
125.0	4.988	.002	71062.	71.
130.0	4.996	.002	71417.	71.
135.0	5.003	.002	71774.	72.
140.0	5.011	.002	72133.	72.
145.0	5.019	.002	72494.	72.
150.0	5.027	.000	72856.	73.
155.0	5.027	.002	73220.	73.
160.0	5.035	.002	73586.	74.
165.0	5.043	.002	73954.	74.
170.0	5.052	.002	74324.	74.
175.0	5.060	.002	74696.	75.
180.0	5.068	.002	75069.	75.
185.0	5.077	.002	75444.	75.
190.0	5.085	.002	75822.	76.
195.0	5.093	.002	76201.	76.
200.0	5.102	.002	76582.	77.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
205.0	5.110	.002	76965.	77.
210.0	5.118	.002	77349.	77.
215.0	5.126	.000	77736.	78.
220.0	5.127	.002	78125.	78.
225.0	5.136	.002	78515.	79.
230.0	5.145	.002	78908.	79.
235.0	5.154	.002	79302.	79.
240.0	5.163	.002	79699.	80.
245.0	5.172	.002	80097.	80.
250.0	5.181	.002	80498.	80.
255.0	5.190	.002	80900.	81.
260.0	5.199	.002	81305.	81.
265.0	5.208	.002	81711.	82.
270.0	5.217	.002	82120.	82.
275.0	5.225	.000	82530.	83.
280.0	5.226	.002	82943.	83.
285.0	5.236	.002	83357.	83.
290.0	5.245	.002	83774.	84.
295.0	5.255	.002	84193.	84.
300.0	5.265	.002	84614.	85.
305.0	5.274	.002	85037.	85.
310.0	5.284	.002	85462.	85.
315.0	5.294	.002	85889.	86.
320.0	5.303	.002	86319.	86.
325.0	5.313	.002	86750.	87.
330.0	5.322	.000	87184.	87.
335.0	5.323	.002	87620.	88.
340.0	5.333	.002	88058.	88.
345.0	5.344	.002	88498.	88.
350.0	5.354	.002	88941.	89.
355.0	5.364	.002	89385.	89.
360.0	5.375	.002	89832.	90.
365.0	5.385	.002	90281.	90.
370.0	5.395	.002	90733.	91.
375.0	5.406	.002	91186.	91.
380.0	5.416	.002	91642.	92.
385.0	5.426	.001	92101.	92.
390.0	5.431	.002	92561.	93.
395.0	5.442	.002	93024.	93.
400.0	5.453	.002	93489.	93.

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BISON STRAIN GAGE INSTRUMENT
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
405.0	5.464	.002	93956.	94.
410.0	5.475	.002	94426.	94.
415.0	5.486	.002	94898.	95.
420.0	5.497	.002	95373.	95.
425.0	5.508	.002	95849.	96.
430.0	5.519	.002	96329.	96.
435.0	5.530	.001	96810.	97.
440.0	5.537	.002	97294.	97.
445.0	5.548	.002	97781.	98.
450.0	5.560	.002	98270.	98.
455.0	5.572	.002	98761.	99.
460.0	5.584	.002	99255.	99.
465.0	5.596	.002	99751.	100.
470.0	5.607	.002	100250.	100.
475.0	5.619	.002	100751.	101.
480.0	5.631	.001	101255.	101.
485.0	5.637	.003	101761.	102.
490.0	5.650	.003	102270.	102.
495.0	5.662	.003	102781.	103.
500.0	5.675	.003	103295.	103.
505.0	5.687	.003	103811.	104.
510.0	5.700	.003	104330.	104.
515.0	5.713	.003	104852.	105.
520.0	5.725	.001	105376.	105.
525.0	5.729	.003	105903.	106.
530.0	5.742	.003	106432.	106.
535.0	5.756	.003	106965.	107.
540.0	5.770	.003	107499.	107.
545.0	5.783	.003	108037.	108.
550.0	5.797	.003	108577.	109.
555.0	5.810	.003	109120.	109.
560.0	5.824	.002	109665.	110.
565.0	5.836	.003	110214.	110.
570.0	5.850	.003	110765.	111.
575.0	5.864	.003	111319.	111.
580.0	5.878	.003	111875.	112.
585.0	5.892	.003	112434.	112.
590.0	5.906	.003	112997.	113.
595.0	5.921	.001	113562.	114.
600.0	5.928	.003	114129.	114.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
605.0	5.943	.003	114700.	115.
610.0	5.958	.003	115273.	115.
615.0	5.973	.003	115850.	116.
620.0	5.988	.003	116429.	116.
625.0	6.003	.003	117011.	117.
630.0	6.018	.003	117596.	118.
635.0	6.033	.004	118184.	118.
640.0	6.051	.003	118775.	119.
645.0	6.066	.003	119369.	119.
650.0	6.081	.003	119965.	120.
655.0	6.097	.003	120565.	121.
660.0	6.112	.003	121168.	121.
665.0	6.127	.002	121774.	122.
670.0	6.138	.003	122383.	122.
675.0	6.154	.003	122995.	123.
680.0	6.171	.003	123609.	124.
685.0	6.187	.003	124227.	124.
690.0	6.203	.003	124849.	125.
695.0	6.220	.003	125473.	125.
700.0	6.236	.003	126100.	126.
705.0	6.253	.003	126731.	127.
710.0	6.270	.003	127364.	127.
715.0	6.288	.003	128001.	128.
720.0	6.305	.003	128641.	129.
725.0	6.322	.001	129284.	129.
730.0	6.328	.004	129931.	130.
735.0	6.347	.004	130580.	131.
740.0	6.366	.004	131233.	131.
745.0	6.384	.004	131889.	132.
750.0	6.403	.004	132549.	133.
755.0	6.422	.002	133211.	133.
760.0	6.431	.004	133877.	134.
765.0	6.452	.004	134547.	135.
770.0	6.473	.004	135219.	135.
775.0	6.493	.004	135895.	136.
780.0	6.514	.004	136575.	137.
785.0	6.534	.004	137258.	137.
790.0	6.555	.004	137944.	138.
795.0	6.576	.004	138634.	139.
800.0	6.598	.004	139327.	139.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*2*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
805.0	6.620	.004	140023.	140.
810.0	6.641	.004	140723.	141.
815.0	6.662	.005	141427.	141.
820.0	6.685	.005	142134.	142.
825.0	6.707	.005	142845.	143.
830.0	6.730	.003	143559.	144.
835.0	6.745	.005	144277.	144.
840.0	6.769	.005	144998.	145.
845.0	6.793	.005	145723.	146.
850.0	6.817	.005	146452.	146.
855.0	6.841	.005	147184.	147.
860.0	6.865	.005	147920.	148.
865.0	6.889	.005	148659.	149.
870.0	6.913	.005	149403.	149.
875.0	6.938	.004	150150.	150.
880.0	6.960	.005	150900.	151.
885.0	6.986	.005	151655.	152.
890.0	7.012	.005	152413.	152.
895.0	7.039	.006	153175.	153.
900.0	7.068	.006	153941.	154.
905.0	7.095	.006	154711.	155.
910.0	7.123	.004	155484.	155.
915.0	7.141	.006	156261.	156.
920.0	7.171	.006	157043.	157.
925.0	7.202	.006	157828.	158.
930.0	7.233	.007	158617.	159.
935.0	7.265	.006	159410.	159.
940.0	7.298	.006	160207.	160.
945.0	7.330	.006	161008.	161.
950.0	7.360	.007	161813.	162.
955.0	7.395	.007	162622.	163.
960.0	7.430	.008	163435.	163.
965.0	7.470	.007	164252.	164.
970.0	7.504	.007	165074.	165.
975.0	7.539	.010	165899.	166.
980.0	7.590	.006	166728.	167.
985.0	7.621	.008	167562.	168.
990.0	7.663	.006	168400.	168.
995.0	7.692	.006	169242.	169.
1000.0	7.720	****	170088.	170.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 1*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
540.0	4.496	.003	11402.	13.
545.0	4.513	.003	11469.	13.
550.0	4.529	.003	11536.	13.
555.0	4.546	.003	11603.	13.
560.0	4.562	.003	11671.	13.
565.0	4.578	.003	11738.	13.
570.0	4.595	.003	11805.	13.
575.0	4.611	.004	11872.	13.
580.0	4.632	.003	11939.	13.
585.0	4.648	.003	12006.	12.
590.0	4.665	.003	12066.	13.
595.0	4.682	.003	12129.	18.
600.0	4.699	.003	12218.	18.
605.0	4.716	.003	12307.	12.
610.0	4.731	.004	12368.	12.
615.0	4.749	.004	12430.	12.
620.0	4.767	.004	12492.	14.
625.0	4.784	.004	12562.	21.
630.0	4.802	.004	12667.	21.
635.0	4.819	.003	12771.	13.
640.0	4.836	.004	12835.	13.
645.0	4.855	.004	12899.	13.
650.0	4.873	.004	12963.	23.
655.0	4.891	.004	13077.	13.
660.0	4.910	.003	13144.	27.
665.0	4.925	.004	13278.	27.
670.0	4.944	.004	13412.	27.
675.0	4.963	.004	13545.	27.
680.0	4.982	.004	13679.	27.
685.0	5.002	.004	13813.	27.
690.0	5.021	.005	13947.	27.
695.0	5.047	.004	14081.	50.
700.0	5.066	.004	14331.	25.
705.0	5.086	.004	14455.	18.
710.0	5.106	.002	14547.	25.
715.0	5.115	.004	14672.	25.
720.0	5.136	.004	14798.	25.
725.0	5.158	.004	14923.	25.
730.0	5.180	.004	15048.	25.
735.0	5.201	.004	15173.	25.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 1*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
740.0	5.223	.005	15299.	25.
745.0	5.250	.004	15424.	42.
750.0	5.273	.004	15634.	26.
755.0	5.295	.004	15763.	26.
760.0	5.317	.003	15891.	16.
765.0	5.333	.005	15970.	21.
770.0	5.357	.005	16076.	30.
775.0	5.382	.005	16224.	30.
780.0	5.406	.004	16372.	30.
785.0	5.427	.005	16519.	28.
790.0	5.453	.005	16661.	31.
795.0	5.479	.005	16816.	17.
800.0	5.505	.005	16900.	25.
805.0	5.531	.007	17025.	35.
810.0	5.567	.005	17201.	35.
815.0	5.594	.005	17377.	35.
820.0	5.620	.005	17553.	35.
825.0	5.642	.006	17729.	34.
830.0	5.671	.006	17901.	43.
835.0	5.699	.006	18113.	43.
840.0	5.727	.007	18326.	18.
845.0	5.761	.006	18418.	35.
850.0	5.791	.006	18593.	59.
855.0	5.820	.006	18887.	27.
860.0	5.848	.006	19021.	65.
865.0	5.880	.006	19346.	65.
870.0	5.912	.006	19671.	66.
875.0	5.941	.007	20000.	67.
880.0	5.975	.007	20334.	67.
885.0	6.009	.007	20667.	110.
890.0	6.045	.007	21219.	55.
895.0	6.080	.007	21493.	55.
900.0	6.115	.008	21767.	55.
905.0	6.154	.007	22041.	105.
910.0	6.191	.007	22565.	26.
915.0	6.228	.009	22695.	51.
920.0	6.273	.008	22952.	51.
925.0	6.311	.007	23208.	51.
930.0	6.345	.008	23465.	51.
935.0	6.386	.008	23722.	59.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 1*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
940.0	6.428	.010	24018.	44.
945.0	6.480	.008	24236.	78.
950.0	6.522	.009	24624.	60.
955.0	6.567	.009	24925.	92.
960.0	6.612	.010	25387.	94.
965.0	6.663	.009	25859.	94.
970.0	6.708	.011	26330.	94.
975.0	6.765	.008	26801.	138.
980.0	6.807	.012	27490.	128.
985.0	6.867	.006	28132.	58.
990.0	6.899	.006	28423.	58.
995.0	6.930	****	28714.	29.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
10.0	6.583	.002	24519.	25.
15.0	6.595	.002	24641.	25.
20.0	6.607	.002	24765.	25.
25.0	6.619	.002	24889.	25.
30.0	6.631	.002	25013.	25.
35.0	6.643	.002	25138.	25.
40.0	6.655	.002	25264.	25.
45.0	6.668	.002	25390.	25.
50.0	6.680	.002	25517.	26.
55.0	6.692	.002	25645.	26.
60.0	6.704	.002	25773.	26.
65.0	6.716	.004	25902.	26.
70.0	6.734	.002	26031.	26.
75.0	6.746	.002	26161.	26.
80.0	6.758	.002	26292.	26.
85.0	6.770	.002	26424.	26.
90.0	6.782	.002	26556.	27.
95.0	6.794	.002	26688.	27.
100.0	6.806	.001	26822.	27.
105.0	6.812	.003	26956.	27.
110.0	6.825	.003	27091.	27.
115.0	6.837	.003	27226.	27.
120.0	6.850	.003	27362.	27.
125.0	6.862	.003	27499.	27.
130.0	6.875	.003	27637.	28.
135.0	6.887	.003	27775.	28.
140.0	6.900	.003	27914.	28.
145.0	6.912	.003	28053.	28.
150.0	6.927	.003	28194.	28.
155.0	6.939	.003	28335.	28.
160.0	6.952	.003	28476.	28.
165.0	6.965	.003	28619.	29.
170.0	6.978	.003	28762.	29.
175.0	6.991	.003	28905.	29.
180.0	7.003	.003	29050.	29.
185.0	7.016	.003	29195.	29.
190.0	7.030	.003	29341.	29.
195.0	7.043	.003	29488.	29.
200.0	7.056	.003	29635.	30.
205.0	7.070	.003	29784.	30.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
210.0	7.083	.003	29932.	30.
215.0	7.096	.003	30082.	30.
220.0	7.109	.001	30232.	30.
225.0	7.116	.003	30384.	30.
230.0	7.130	.003	30536.	31.
235.0	7.144	.003	30688.	31.
240.0	7.158	.003	30842.	31.
245.0	7.172	.003	30996.	31.
250.0	7.186	.003	31151.	31.
255.0	7.200	.003	31307.	31.
260.0	7.214	.003	31463.	31.
265.0	7.227	.003	31620.	32.
270.0	7.242	.003	31779.	32.
275.0	7.257	.003	31937.	32.
280.0	7.271	.003	32097.	32.
285.0	7.286	.003	32258.	32.
290.0	7.301	.003	32419.	32.
295.0	7.315	.003	32581.	33.
300.0	7.329	.003	32744.	33.
305.0	7.344	.003	32908.	33.
310.0	7.359	.003	33072.	33.
315.0	7.375	.003	33238.	33.
320.0	7.390	.003	33404.	33.
325.0	7.405	.002	33571.	34.
330.0	7.413	.003	33739.	34.
335.0	7.430	.003	33907.	34.
340.0	7.446	.003	34077.	34.
345.0	7.462	.003	34247.	34.
350.0	7.478	.003	34418.	34.
355.0	7.494	.003	34591.	35.
360.0	7.510	.003	34763.	35.
365.0	7.527	.003	34937.	35.
370.0	7.544	.003	35112.	35.
375.0	7.560	.003	35288.	35.
380.0	7.577	.003	35464.	35.
385.0	7.593	.003	35641.	36.
390.0	7.610	.003	35819.	36.
395.0	7.625	.003	35999.	36.
400.0	7.643	.003	36179.	36.
405.0	7.660	.003	36359.	36.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
410.0	7.677	.003	36541.	37.
415.0	7.694	.003	36724.	37.
420.0	7.711	.003	36908.	37.
425.0	7.726	.004	37092.	37.
430.0	7.744	.004	37278.	37.
435.0	7.762	.004	37464.	37.
440.0	7.780	.004	37651.	38.
445.0	7.798	.004	37840.	38.
450.0	7.816	.004	38029.	38.
455.0	7.835	.004	38219.	38.
460.0	7.854	.004	38410.	38.
465.0	7.873	.004	38602.	39.
470.0	7.891	.004	38795.	39.
475.0	7.910	.003	38989.	39.
480.0	7.927	.004	39184.	39.
485.0	7.946	.004	39380.	39.
490.0	7.965	.004	39577.	40.
495.0	7.985	.004	39775.	40.
500.0	8.004	.004	39973.	40.
505.0	8.024	.005	40173.	40.
510.0	8.050	.004	40374.	40.
515.0	8.070	.004	40576.	41.
520.0	8.089	.004	40779.	41.
525.0	8.109	.003	40983.	41.
530.0	8.122	.004	41188.	41.
535.0	8.143	.004	41394.	41.
540.0	8.164	.004	41601.	42.
545.0	8.185	.004	41809.	42.
550.0	8.206	.004	42018.	42.
555.0	8.224	.004	42228.	42.
560.0	8.246	.004	42439.	42.
565.0	8.268	.004	42651.	43.
570.0	8.290	.004	42864.	43.
575.0	8.312	.005	43079.	43.
580.0	8.338	.005	43294.	43.
585.0	8.361	.005	43511.	44.
590.0	8.383	.005	43728.	44.
595.0	8.406	.004	43947.	44.
600.0	8.425	.005	44166.	44.
605.0	8.449	.005	44387.	44.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
610.0	8.473	.005	44609.	45.
615.0	8.497	.005	44832.	45.
620.0	8.520	.006	45056.	45.
625.0	8.550	.005	45282.	45.
630.0	8.574	.005	45508.	48.
635.0	8.599	.005	45747.	67.
640.0	8.623	.005	46082.	75.
645.0	8.650	.005	46458.	75.
650.0	8.675	.005	46834.	75.
655.0	8.700	.005	47210.	75.
660.0	8.725	.006	47587.	122.
665.0	8.756	.005	48195.	73.
670.0	8.782	.005	48562.	73.
675.0	8.808	.004	48929.	73.
680.0	8.829	.005	49296.	73.
685.0	8.856	.005	49663.	98.
690.0	8.883	.005	50152.	50.
695.0	8.911	.006	50403.	50.
700.0	8.940	.006	50655.	78.
705.0	8.969	.006	51046.	85.
710.0	8.997	.006	51469.	85.
715.0	9.025	.007	51892.	129.
720.0	9.061	.006	52539.	77.
725.0	9.090	.006	52926.	77.
730.0	9.119	.006	53312.	81.
735.0	9.149	.006	53715.	80.
740.0	9.179	.006	54115.	80.
745.0	9.209	.006	54514.	77.
750.0	9.238	.006	54897.	88.
755.0	9.270	.006	55338.	88.
760.0	9.302	.006	55778.	88.
765.0	9.334	.009	56219.	94.
770.0	9.381	.006	56690.	91.
775.0	9.412	.005	57147.	57.
780.0	9.439	.007	57433.	88.
785.0	9.472	.007	57873.	114.
790.0	9.506	.007	58440.	90.
795.0	9.540	.007	58889.	122.
800.0	9.575	.007	59498.	122.
805.0	9.611	.008	60107.	122.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 2*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
810.0	9.650	.007	60716.	61.
815.0	9.687	.007	61019.	118.
820.0	9.724	.009	61612.	67.
825.0	9.768	.008	61949.	283.
830.0	9.805	.007	63363.	283.
835.0	9.839	.008	64778.	242.
840.0	9.880	.008	65988.	426.
845.0	9.920	.010	68117.	210.
850.0	9.972	.008	69168.	210.
855.0	10.012	.009	70218.	210.
860.0	10.057	.008	71269.	210.
865.0	10.098	.008	72319.	210.
870.0	10.140	.012	73370.	339.
875.0	10.199	.008	75064.	169.
880.0	10.240	.010	75907.	96.
885.0	10.290	.009	76387.	184.
890.0	10.332	.010	77306.	205.
895.0	10.383	.009	78332.	172.
900.0	10.427	.010	79192.	172.
905.0	10.477	.009	80051.	192.
910.0	10.523	.010	81009.	225.
915.0	10.574	.010	82136.	198.
920.0	10.622	.011	83127.	198.
925.0	10.678	.010	84117.	237.
930.0	10.728	.012	85302.	250.
935.0	10.787	.010	86550.	198.
940.0	10.839	.013	87540.	255.
945.0	10.904	.011	88816.	191.
950.0	10.957	.014	89773.	239.
955.0	11.027	.011	90967.	170.
960.0	11.081	.011	91816.	258.
965.0	11.138	.015	93108.	263.
970.0	11.213	.012	94424.	281.
975.0	11.274	.010	95831.	284.
980.0	11.325	.014	97249.	397.
985.0	11.396	.004	99233.	113.
990.0	11.418	****	99796.	100.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
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INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
30.0	9.788	.003	62167.	105.
35.0	9.802	.003	62692.	105.
40.0	9.817	.003	63216.	105.
45.0	9.832	.003	63741.	105.
50.0	9.847	.003	64265.	105.
55.0	9.861	.003	64790.	105.
60.0	9.876	.003	65314.	226.
65.0	9.891	.003	66444.	87.
70.0	9.906	.004	66878.	87.
75.0	9.926	.003	67312.	87.
80.0	9.940	.003	67746.	87.
85.0	9.955	.003	68180.	87.
90.0	9.970	.003	68614.	87.
95.0	9.984	.003	69048.	87.
100.0	9.999	.003	69482.	87.
105.0	10.013	.004	69916.	87.
110.0	10.035	.003	70350.	87.
115.0	10.049	.003	70784.	87.
120.0	10.064	.003	71218.	87.
125.0	10.078	.003	71652.	372.
130.0	10.093	.003	73514.	74.
135.0	10.107	.002	73882.	74.
140.0	10.117	.003	74251.	74.
145.0	10.132	.003	74622.	75.
150.0	10.147	.003	74995.	75.
155.0	10.163	.003	75370.	75.
160.0	10.178	.003	75747.	76.
165.0	10.193	.003	76126.	76.
170.0	10.208	.003	76506.	77.
175.0	10.223	.003	76889.	77.
180.0	10.239	.003	77273.	77.
185.0	10.254	.003	77660.	78.
190.0	10.270	.003	78048.	78.
195.0	10.285	.003	78438.	78.
200.0	10.301	.003	78830.	79.
205.0	10.317	.004	79224.	79.
210.0	10.336	.003	79621.	80.
215.0	10.352	.003	80019.	80.
220.0	10.368	.003	80419.	80.
225.0	10.384	.003	80821.	81.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
230.0	10.399	.003	81225.	81.
235.0	10.415	.003	81631.	82.
240.0	10.430	.003	82039.	82.
245.0	10.447	.003	82449.	82.
250.0	10.463	.003	82861.	83.
255.0	10.479	.003	83276.	83.
260.0	10.496	.003	83692.	84.
265.0	10.512	.003	84110.	84.
270.0	10.528	.003	84531.	85.
275.0	10.545	.003	84954.	85.
280.0	10.562	.003	85378.	85.
285.0	10.579	.003	85805.	86.
290.0	10.596	.003	86234.	86.
295.0	10.613	.003	86665.	87.
300.0	10.630	.004	87099.	87.
305.0	10.648	.004	87534.	88.
310.0	10.665	.004	87972.	88.
315.0	10.683	.004	88411.	88.
320.0	10.701	.004	88853.	89.
325.0	10.718	.004	89298.	89.
330.0	10.738	.004	89744.	90.
335.0	10.756	.004	90193.	90.
340.0	10.774	.004	90644.	91.
345.0	10.793	.004	91097.	91.
350.0	10.811	.003	91552.	92.
355.0	10.825	.004	92010.	92.
360.0	10.844	.004	92470.	92.
365.0	10.863	.004	92932.	93.
370.0	10.882	.004	93397.	93.
375.0	10.901	.004	93864.	94.
380.0	10.920	.005	94333.	94.
385.0	10.945	.004	94805.	95.
390.0	10.964	.004	95279.	95.
395.0	10.983	.004	95755.	96.
400.0	11.003	.004	96234.	96.
405.0	11.022	.004	96715.	97.
410.0	11.043	.004	97199.	97.
415.0	11.063	.004	97685.	98.
420.0	11.082	.004	98173.	98.
425.0	11.102	.004	98664.	99.

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BISON STRAIN GAGE INSTRUMENT

CALIBRATION TABLES

****

INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES

SENSOR PAIR NUMBER* 3**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
430.0	11.122	.004	99157.	99.
435.0	11.144	.004	99653.	100.
440.0	11.164	.004	100151.	100.
445.0	11.185	.004	100652.	101.
450.0	11.205	.003	101155.	101.
455.0	11.218	.004	101661.	102.
460.0	11.240	.004	102169.	102.
465.0	11.262	.004	102680.	103.
470.0	11.284	.004	103193.	103.
475.0	11.305	.005	103709.	104.
480.0	11.328	.004	104228.	104.
485.0	11.350	.004	104749.	105.
490.0	11.372	.004	105273.	105.
495.0	11.395	.004	105799.	106.
500.0	11.417	.006	106328.	106.
505.0	11.446	.004	106860.	107.
510.0	11.468	.004	107394.	107.
515.0	11.491	.004	107931.	108.
520.0	11.513	.004	108470.	108.
525.0	11.535	.005	109013.	109.
530.0	11.558	.005	109558.	110.
535.0	11.582	.005	110105.	110.
540.0	11.605	.004	110656.	111.
545.0	11.626	.005	111209.	111.
550.0	11.651	.005	111765.	112.
555.0	11.675	.005	112324.	112.
560.0	11.700	.005	112886.	113.
565.0	11.724	.007	113450.	113.
570.0	11.759	.005	114017.	114.
575.0	11.783	.005	114587.	115.
580.0	11.808	.004	115160.	115.
585.0	11.828	.005	115736.	116.
590.0	11.854	.005	116314.	116.
595.0	11.880	.005	116896.	117.
600.0	11.905	.005	117480.	117.
605.0	11.931	.005	118068.	118.
610.0	11.958	.005	118658.	119.
615.0	11.984	.005	119251.	119.
620.0	12.011	.007	119848.	120.
625.0	12.044	.005	120447.	120.

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BISON STRAIN GAGE INSTRUMENT
CALIBRATION TABLES
****

INSTRUMENT NUMBER* 4*SENSOR DIAMETER*4*INCHES
SENSOR PAIR NUMBER* 3**RANGE* 3*

AMPLITUDE DIAL	SENSOR SPACING	INCHES/DIAL READING	MICROSTRAIN	MICROSTRAIN/DIAL READING
630.0	12.070	.005	121049.	121.
635.0	12.096	.005	121654.	122.
640.0	12.122	.008	122262.	122.
645.0	12.164	.005	122874.	123.
650.0	12.187	.005	123488.	123.
655.0	12.211	.007	124105.	124.
660.0	12.245	.004	124726.	125.
665.0	12.267	.004	125350.	125.
670.0	12.290	.004	125976.	126.
675.0	12.312	****	126606.	127.

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APPENDIX B
NORTH FIELD CRATER INSTRUMENTATION DATA REPORT

INTRODUCTION

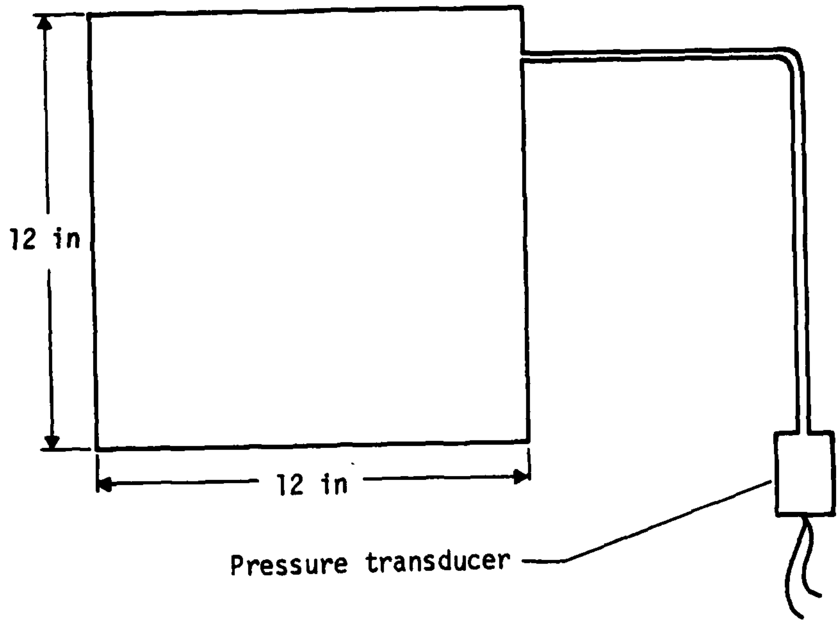
To verify the results of the New Mexico Engineering Research Institute (NMERI) Bomb Damage Repair (BDR) computer code, which predicts the response of repaired bomb craters to aircraft loads, a crater instrumentation plan was developed. The instrumentation plan defined the types of data measurements that should be made during field testing of a repaired crater. These data could then be used for comparison with and verification of the NMERI BDR code predictions, specifically deflection, stress, and strain.

The instrumentation plan as originally contracted to NMERI required a recommended list of measurements and requisition and/or fabrication of the instrumentation necessary for NMERI BDR code verification. After acquiring the equipment, NMERI was to instruct AFESC technicians and engineers on instrumentation installation and operation. As a result of personnel changes at AFESC, the NMERI contract was amended to include instrumentation of one crater at the North Field, South Carolina, test site. NMERI was unable to perform detailed evaluations of the recommended instrumentation prior to the North Field test because of the restricted time schedule. Also some of the recommended instrumentation was not available due to manufacturers' delivery problems. The result was the placement of six instruments in the crater at North Field to record pressure in the crushed limestone layer due to load cart and aircraft traffic.

CRATER INSTRUMENTATION

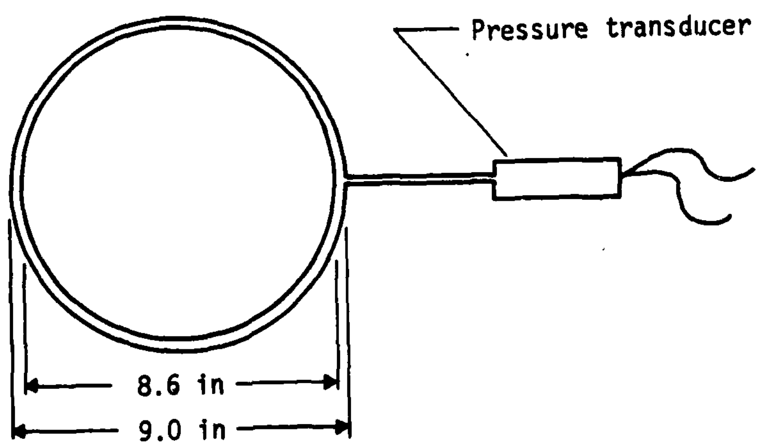
As a result of equipment requisition and availability problems, only pressure gages were placed in the large crater at North Field. The pressure gages, termed "flatjack" pressure gages and shown in Figure B-1, were manufactured by two companies, Terra Tek of Salt Lake City, Utah, and Geokon of West Lebanon, New Hampshire. These gages were calibrated by NMERI for both static and dynamic response.

The static calibration test consisted of recording the analog output of the gage as the load on the gage was slowly increased. The results of these tests indicated a linear response between the gage output and applied load, Terra Tek "flatjack" pressure gage



Gage thickness approximately 1/8 in.

Geokon "flatjack" pressure gage



Gage thickness approximately 3/8 in.

Figure B-1. Crater Pressure Gages.

except at low stress levels where boundary conditions of gage construction caused nonlinear behavior. Data recorded at North Field that were considered to be in this nonlinear range are indicated by an "x" following the data values in Tables B-1 through B-3. The following is a brief description of the terms used in the tables:

- Pass No. = the pass number during the first 10 coverages (96 passes) after compaction of the crushed limestone, corresponding to a maximum pressure as indicated by the pressure gage output
- T = Terra Tek gage
- G = Geokon gage
- 1, 2, ... = gage number
- x = pressure value is in nonlinear range of gage as indicated by static calibration curves
- OP No. = operation number
- OP type = operation type
  - TX = taxi (east-to-west direction)
  - TXR = taxi, return (west-to-east direction)
  - T/G = touch and go
  - TO = takeoff
  - L = landing
  - ST = static
- Offset = center-main gear distance offset specified as feet-inches

Dynamic calibrations were performed on one gage by placing the gage in Ottawa sand, loading the sand via a large diameter plate, and utilizing the NMERI Instron dynamic testing equipment to vary the frequency of the applied load. These tests were performed at different frequency ranges and indicated a decreasing gage voltage output with increasing frequency.

Four Terra Tek and two Geokon pressure gages were placed in a large crater at North Field as shown in Figure B-2. Terra Tek gages are indicated by a square (Nos. 1, 2, 3, and 4); Geokon gages are indicated by a circle (Nos. 5 and 6). The gages were arranged to account for aircraft wander, and measurement of pressure attenuation and distribution within the crushed limestone layer.

TABLE B-1. UNCORRECTED F4 LOAD CART PEAK PRESSURE DATA.

Pass No.	Peak pressure, lb/in^2					
	T-1	T-2	T-3	T-4	G-5	G-6
6	[a]54.58	[a]52.77	0.38x	1.68	0.71x	1.99x
10	5.83	1.79	1.03x	[a]31.55	0.61x	[a]36.04
14	0	0	[a]38.54	6.29	[a]33.36	8.16x
34	0	0	[a]52.63	5.67	[a]33.59	8.96x
37	3.69	0.99	0.94x	[a]33.21	4.07x	[a]41.02
38	1.17	0.60	1.69x	[a]43.63	1.63x	[a]48.18
42	[a]69.89	[a]48.01	0.29x	1.76	0.30x	1.70x
48	[a]67.58	[a]35.72	0.29x	2.55	0.30x	2.99x
52	3.11	0.39x	2.06x	[a]47.55	1.83x	[a]44.80
54	0	0	14.48	[a]30.47	8.14x	[a]31.24
56	0	0	[a]55.36	4.33	[a]39.28	6.37x
74	0	0	[a]60.14	2.16	[a]53.92	3.19x
78	0.59x	0	3.57x	[a]53.84	2.65x	[a]51.17
81	[a]64.86	[a]37.31	0	1.28	0.71x	1.80x
84	[a]58.25	[a]72.23	0.75x	0.69x	1.42x	0.70x
89	0.96	0	4.23	[a]34.98	3.06x	[a]56.15
92	0	0	[a]60.89	5.50	[a]43.14	8.17x
$\bar{x}$	63.03	49.21	53.21	39.32	40.66	44.09
SD	6.43	14.73	9.04	9.06	8.47	8.68
$\bar{x}$	56.12		45.23		42.66	
SD	12.96		11.31		8.39	
$\bar{x}$			43.95			
SD			9.82			

a. Peak pressure recorded when the load cart passed above the gage.

TABLE B-2. UNCORRECTED F4 AIRCRAFT PEAK PRESSURE DATA.

OP No.	OP type	Offset, ft-in	Peak pressure, lb/in²					
			T-1	T-2	T-3	T-4	G-5	G-6
1	TX	8-9	0	0	2.34x	6.24	3.28x	24.88
2	TX	9-0	0.43x	0	1.88x	7.33	3.92x	28.19
9	TX	9-0	0	0	3.85	4.53	13.68	17.57
10	TO	9-9	2.48	0	0.93x	8.15	2.99x	>32.38
17	TO	10-3	3.58	0	0.23x	2.26	0.95x	17.72
18	T/G	8-1	0	0	0.72x	0	5.75x	10.56
19	L	11-9	35.70	1.72	0	0	0	0.40x
20	TO	9-6	0.59x	0	1.29x	6.55	3.68x	24.25

TABLE B-3. UNCORRECTED C130 AIRCRAFT PEAK PRESSURE DATA.

OP No.	OP type	Offset, ft-in	Peak pressure, lb/in²					
			T-1	T-2	T-3	T-4	G-5	G-6
3	TX	7-0	0	0	1.77x	0	16.16	1.03x
					4.31	0	16.16	0.87x
4	TXR	6-2	0	0	17.53	3.60	26.28	8.39x
					18.96	3.56	22.51	7.60x
5	TX	6-5	0	0	0.38x	0	7.95	0.32x
					0	0	8.44	0.43x
6	TXR	6-3	0	0	8.09	1.32	32.08	4.96x
					12.69	1.63	28.32	4.10x
7	TO	6-6	0	0	0	0	5.67x	0.27x
					0	0	5.10x	0.24x
8	L	6-0	1.71	0	0.57x	0	2.00x	31.73
			1.71		0.83x	0	1.83x	>31.73
11	ST	6-1	0	0	30.66	1.29	28.28	1.66x
					28.96	1.25	29.39	1.59x
12	TX	6-9	0	0	3.84	0.60x	26.25	1.09x
					7.95	0	26.25	0.98x
13	TXR	6-9	0	0	13.60	2.73	29.61	7.63x
					16.47	2.60	24.61	6.30x
14	TX	6-9	0	0	1.29x	0	19.68	0.40x
					2.79x	0	20.25	0.50x
15	TXR	6-9	0	0	3.48	0	26.33	1.18x
					6.20	0	24.72	1.15x
16	L	5-7	0	0	1.40x	0	19.12	0.62x
					2.79x	0	20.81	0.67x

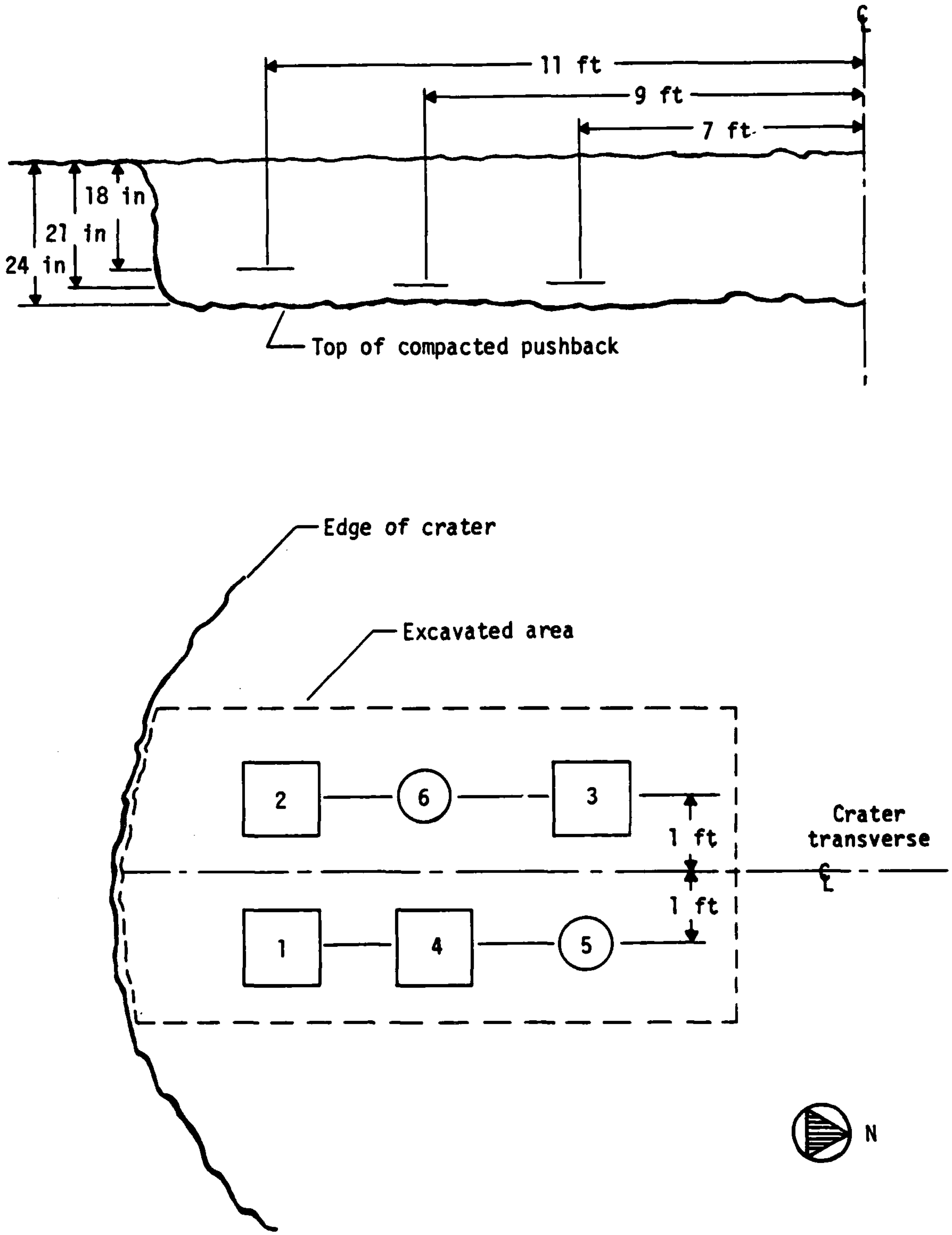


Figure B-2. Pressure Gage Location.

Before placement of the gages, the crushed limestone material was excavated to a depth of 24 inches, corresponding to the top of the compacted pushback material. Seismic velocity measurements were performed on the compacted pushback. Its average propagation velocity was determined to be 1700 ft/s. Assuming a density of 125 lb/ft^3 for the compacted pushback, its elastic modulus was calculated to be 77,900 lb/in^2. Measurements were also made on the crushed limestone material along the longitudinal centerline of the repair area, indicating an average velocity of 1410 ft/s. An elastic modulus was calculated to be 57,900 lb/in^2, assuming a density of 135 lb/ft^3. If a density of 145 lb/ft^3 is used, the corresponding elastic modulus is 64,300 lb/in^2, an increase of 7.4 percent. No density measurements were made on the repair, but 135 to 145 lb/ft^3 are reasonable densities to assume. The velocity measurements indicated a 34-percent greater modulus for the compacted pushback compared to the modulus of the crushed limestone. This is contrary to what was expected. It was presumed that the crushed limestone material would have a higher modulus than the compacted pushback. This may be due to the presence of in situ moisture in the compacted pushback combined with the large amount of traffic over the material by heavy construction equipment, causing the pushback to have a higher modulus than the limestone. The limestone modulus was calculated to be 57,900 lb/in^2, using an average velocity of 1410 ft/s and an assumed density of 135 lb/ft^3. If a higher density of 145 lb/ft^3 and a 3-percent water content are assumed, then the elastic modulus increases to 62,200 lb/in^2. Therefore, it appears that the previously assumed modulus of 100,000 lb/in^2 for the crushed limestone may be inaccurate. Using Hardin's equation to estimate the maximum shear modulus

$$G = \frac{1270\ (2.973 - e)^2}{1 + e}\ OCR^k\ (\bar{\sigma}_0)^{1/2}$$

where

G = shear modulus, lb/in^2

e = void ratio

OCR = overconsolidation ratio

k = a constant depending on plasticity

$\bar{\sigma}_0$ = effective mean principal stress, lb/in^2

Assume a wet unit weight of 145 lb/ft^3, a water content of 3 percent, and a specific gravity of 2.65. The overconsolidation ratio is 1.0 for a granular material and the mean principal stress on the material is 1 lb/in^2. The void ratio for the crushed limestone is calculated to be 0.22, which provides the following equation for the maximum shear modulus:

$$G = 7890\ (\bar{\sigma}_0)^{1/2}$$

For $\bar{\sigma}_0$ = 1 lb/in^2, the maximum shear modulus is 7890 lb/in^2. Increasing the mean principal stress to 7.5 lb/in^2 results in a maximum shear modulus of 21,610 lb/in^2. The elastic modulus is calculated to be 20,510 lb/in^2 and 56,190 lb/in^2, respectively, assuming a Poisson's ratio of 0.3. Thus it appears that the elastic modulus of 100,000 lb/in^2 for the crushed limestone may be a high value. However, if the mean principal stress in the crushed limestone is significantly greater (23.76 lb/in^2) an elastic modulus of 100,000 lb/in^2 is possible. The question lies in the amount of compactive effort or energy retained by the crushed limestone.

The gages were located in the crater as shown in Figure B-2. A native sandy material was used to seat the gages. This material was used on top of the gages to provide good coupling between the gage and the backfill material. After connectivity of the gages was checked, the excavated area was hand backfilled with the previously removed crushed limestone to within 6 to 9 inches of the repair surface. This was done to avoid damage to the gages. At this point a front end loader was used to backfill the remainder of the excavation. When completed, the vibratory roller compacted the limestone and the gage output due to the roller was recorded. Compaction of the limestone followed the recommended AFESC procedures. A sample of the gage output is shown in Figure B-3.

TEST RESULTS

The output of the stress gages due to the vibratory roller, F4 load cart, F4 aircraft, and C130 aircraft was recorded at North Field on analog tape. This tape was digitized and appropriate portions of the data were plotted. Peak stress values (lb/in^2) were determined and are shown in Tables B-1, B-2, and B-3 for the F4 load cart, F4 aircraft, and C130 aircraft, respectively.

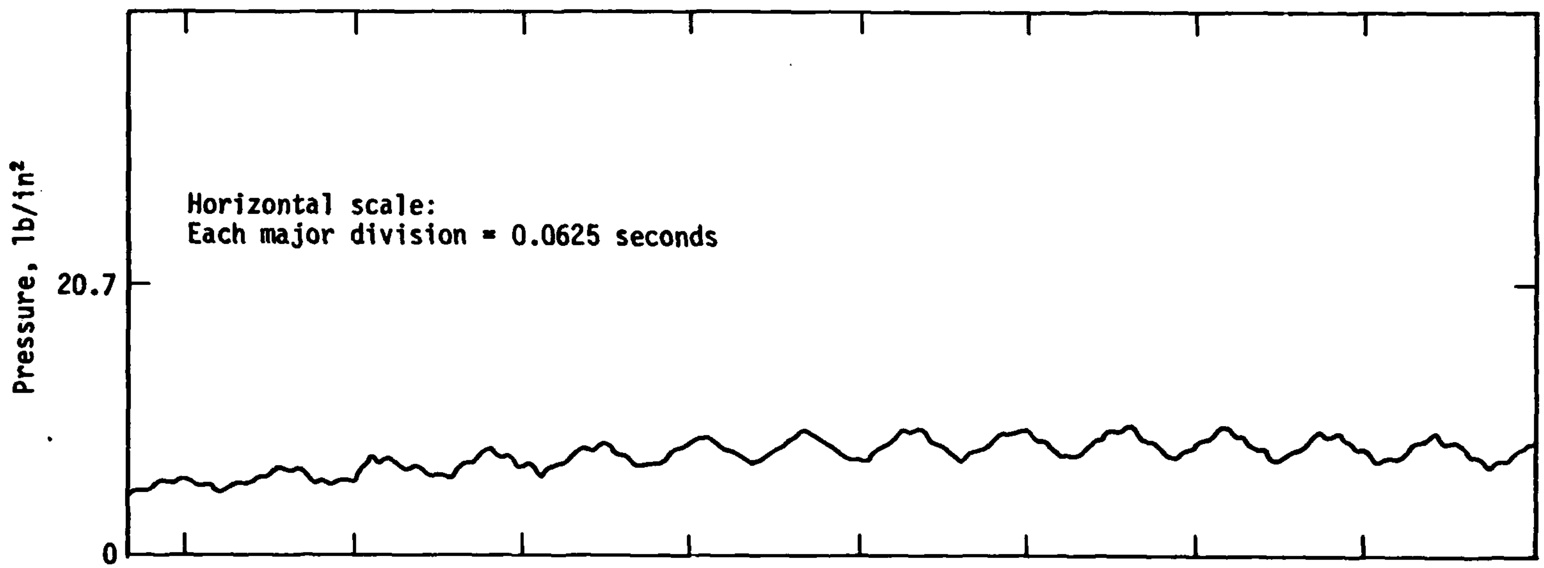


Figure B-3. Gage Output During Compaction.

The 10 coverages placed on the crater repair by the load cart started at the south side of the traffic section, progressed to the north, and then returned to the south (Table B-4). For the F4 aircraft, one coverage is 9.6 passes of the aircraft main gear over a specified width of the crater repair, which accounts for aircraft wander and width of the tire contact area. The traffic area consisted of 12 traffic lanes 10 inches wide and centered at a 9-foot runway centerline offset. Traffic lanes 1 and 12 (south side) received 2 passes; lanes 2, 3, 10, and 11, 8 passes; lanes 4 through 9, 10 passes. The load cart was driven forward in traffic lane 1; this corresponds to pass number 1. Then the load cart was backed over the crater repair, causing a second pass in approximately the same traffic lane. The load cart was then driven forward over traffic lane 2 corresponding to pass number 3 (Table B-4). Table B-1 presents the peak stress recorded by the gages during load cart trafficking.

Due to the inaccuracies of the load cart traffic system, the load cart may not have trafficked each lane twice in the same location. For example, the load cart may have been backed over the crater repair in the same traffic lane or in an adjacent lane. This caused the peak stress due to the load cart to occur on passes that were not perfectly above the gages. Gages T-1 and T-2 are shown in Table B-4 to be beneath traffic lane 4. However, analysis of the recorded data indicated a higher stress when the load cart was in traffic lane 3. Therefore, it was decided that the load cart was more directly over the gages in lane 3 than in lane 4 and the lane 3 data were tabulated. This occurred for gages T-4, G-6, T-3, and G-5.

The values of the peak stress recorded when the load cart passed over the gage (Table B-1) were used to compute the mean $(\bar{x})$ and standard deviation (SD) of the peak stress, presented at the bottom of Table B-1 for each gage and combinations of gages. A value of zero indicates no data were collected or the stress level was insignificant. There was considerable scatter in the data, and standard deviations ranged from a low of 6.43 lb/in^2 for gage T-1 to a high of 14.73 lb/in^2 for gage T-2. Gages T-3, T-4, G-5, and G-6 have standard deviations of 9.04, 9.06, 8.47, and 8.68 lb/in^2, respectively. This may be an indicator of the quality of the gage-backfill coupling, placement technique deviations, or compaction efficiency.

TABLE B-4. F4 LOAD CART TRAFFIC PATTERN FOR 10 COVERAGES.

Gage location				T-1 T-2		T-4 G-6			T-3 G-5			
Traffic lane	1	2	3	4	5	6	7	9	9	10	11	12
Pass No.	1,2	3,4	5,6	7,8	9,10	11,12	13,14	15,16	17,18	19,20	21,22	23,24
		43,44	41,42	39,40	37,38	35,36	33,34	31,32	29,30	27,28	25,26	
		45,46	47,48	49,50	51,52	53,54	55,56	57,58	59,60	61,62	63,64	
		83,84	81,82	79,80	77,78	75,76	73,74	71,72	69,70	67,68	65,66	
				85,86	87,88	89,90	91,92	93,94	95,96			

After completion of the 10 coverages of the crater repair, the load cart was positioned directly above gage T-4 and then above gage G-6 to record static load data. Table B-5 shows the peak pressure values recorded when the load cart was positioned over these gages.

TABLE B-5. STATIC LOAD CART PEAK PRESSURE DATA.

	Gage number					
Load cart position	T-1	T-2	T-3	T-4	G-5	G-6
T-4	0	0	1.13	31.2	5.22	5.81
G-6	0	0	3.57	6.32	1.61	34.54

These data were used to construct a pressure attenuation curve (Figure B-4) that illustrates the peak static stress as a function of distance for the 21-inch depth in the crushed limestone. A line extends through the mean peak pressure values. It can be seen that the peak pressure attenuates rapidly from a value of 32.9 lb/in^2 directly beneath the load to 5.2 lb/in^2 at a distance of 2 feet and 1.4 lb/in^2 at 2.8 feet.

Note that gages T-1 and T-2 indicated no pressure compared to gages T-3 and G-5 that indicated pressures around 5 lb/in^2, all located 2 feet from the load. Two possibilities existed: gages T-1 and T-2 failed, or a discontinuity in the crushed limestone backfill prevented the applied pressure from being distributed to the material around the gages. The first possibility was eliminated, because data were recorded for load cart traffic (Table B-1) when the load cart passed directly over gages T-1 and T-2. Note also a similar trend in the Table B-1 data for gages T-1 and T-2. Therefore, the probable cause for the zero pressure response is a discontinuity in the vicinity of gages T-1 and T-2. Since the instrumentation cables exited the crater repair near gages T-1 and T-2, the vibratory roller operator was advised to use extreme caution to avoid trafficking the cables. In so doing, the crushed limestone material in the vicinity of the cable exit may not have been compacted to the same degree as was the material from the crater's edge. Also, to avoid additional pavement cracking, the roller vibrator was not activated until the roller was some distance into the repair and completely on the crushed limestone. This is another possible cause for a discontinuity to exist near the crater's edge.

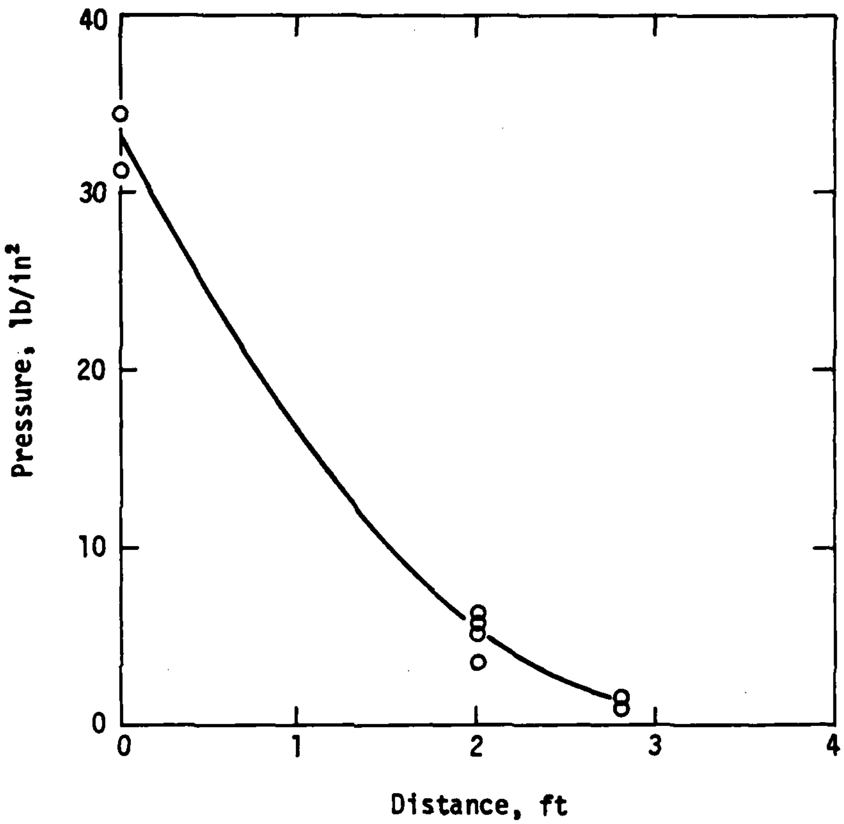


Figure B-4. F4 Load Cart Static Pressure Attenuation At 21-Inch Depth.

Upon comparison of the static peak pressure (Table B-5) with the dynamic load cart data (Table B-1), it was evident that the moving load indicated a greater pressure than the static. This suggested a possible gage resonance response. The collected data were analyzed to determine the principal frequency of the applied dynamic pressure. For a linear system, the frequency is determined using the following equation:

$$f = \frac{0.35}{t_r}$$

where f = frequency of signal (Hz)

t_r = rise time between 10 and 90 percent of the peak response (seconds)

A large number of signals was reviewed and the predominant frequency of the dynamic load cart data was found to be 20 to 25 Hz. An effort was made to evaluate the gage output voltage as a function of frequency, but problems with the dynamic calibration equipment prevented any conclusive data from being collected. After the North Field test, an alternate approach was taken to evaluate the dynamic response characteristics of the gage utilizing digital signal processing and fast Fourier transforms (FFTs). In this method the gage was subjected to an impact load and the corresponding gage response was digitally recorded by a minicomputer. An FFT of the signal was performed that provides the modulus and phase as a function of frequency. By looking at the modulus of the gage signal due to an impact load, peaks can be detected that indicate resonant frequencies of the gage, when compared to troughs or lower modulus values that indicate attenuation frequencies and mean gage performance. Figure B-5 is an example of an FFT from a impact load on a pressure gage, illustrating the mean performance of the gage (dashed line) and a possible resonant frequency of 21 Hz. It is logical to anticipate that the gage will indicate a higher pressure compared to the mean, if the frequency of the induced pressure wave corresponds to a resonant frequency. Thus, a correction factor is necessary to adjust the data for more accurate reflection of the actual stress applied to the gage. The ratio of the modulus at 21 Hz to the mean gage response is approximately 3. A correction factor of one-third was developed for the data collected at North Field. The load cart traffic data (Table B-1) were multiplied by one-third, resulting in the dynamic pressures being approximately 10 to 50 percent of the static pressure (Table B-6).

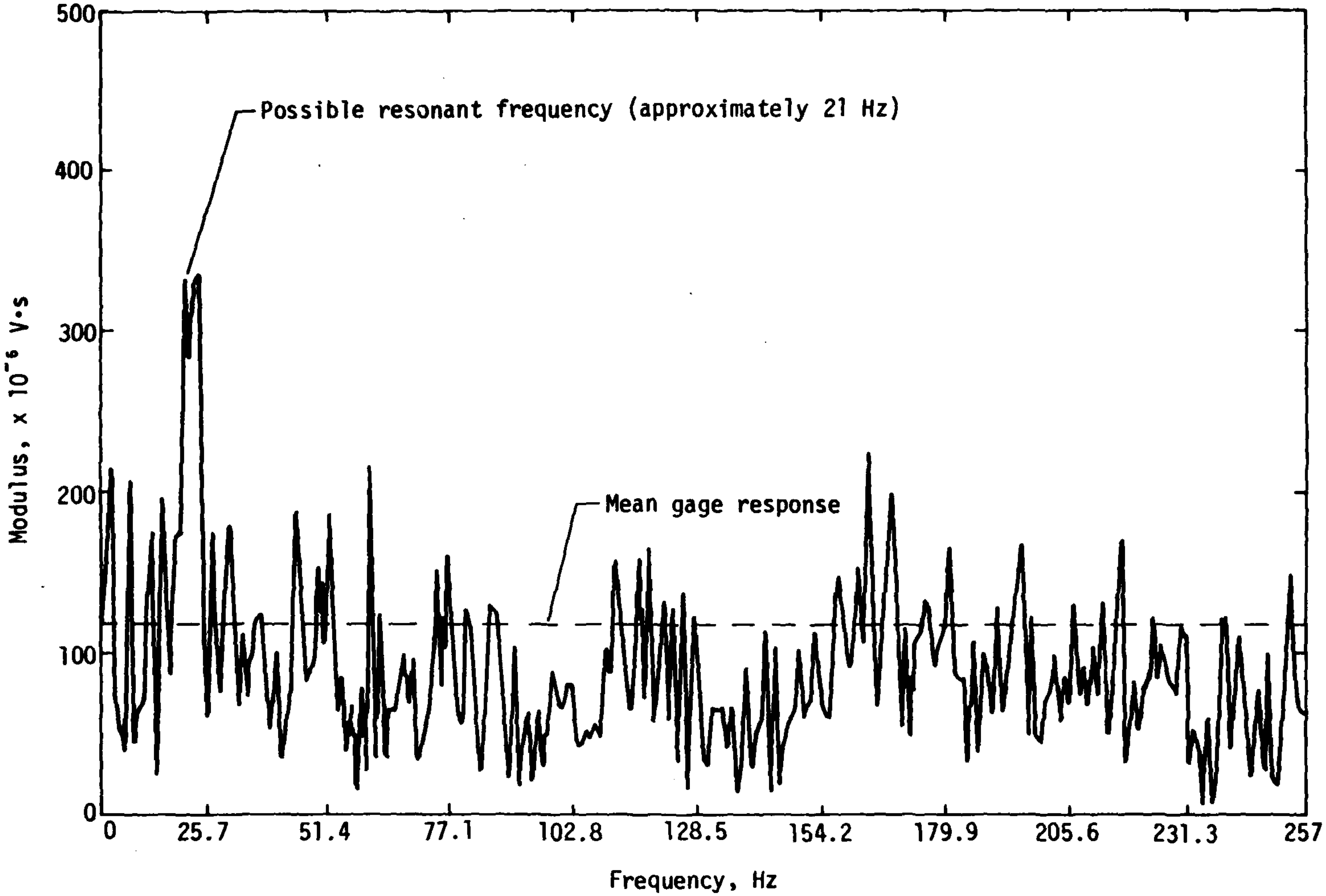


Figure B-5. FFT Of Pressure Gage Output Due To Impulse Load.

TABLE B-6. CORRECTED DYANMIC F4 LOAD CART DATA.

Pass No.	Peak pressure, lb/in^2					
	T-1	T-2	T-3	T-4	G-5	G-6
6	18.20	17.59	0.13	0.56	0.24	0.66
10	1.94	0.60	0.34	10.52	0.20	12.01
14	0	0	12.85	2.10	11.12	2.72
34	0	0	17.55	1.89	11.20	2.99
37	1.23	0.33	0.31	11.07	1.36	13.67
38	0.39	0.20	1.23	14.55	0.54	16.07
42	23.29	16.20	0.10	0.59	0.10	0.57
48	22.53	11.91	0.10	0.85	0.10	1.00
52	1.04	0.13	0.69	15.85	0.61	14.93
54	0	0	4.83	10.16	2.71	10.41
56	0	0	18.45	1.44	13.09	2.12
74	0	0	20.05	0.72	17.97	1.06
78	0.20	0	1.19	17.95	0.88	17.05
81	21.63	12.44	0	0.43	0.24	0.60
84	19.41	24.08	0.25	0.23	0.47	0.23
89	0.96	0	1.41	11.67	1.02	18.72
92	0	0	20.29	1.83	14.39	2.72
$\bar{x}$	21.01	16.40	17.84	13.11	13.55	14.70
SD	2.14	4.91	3.01	3.02	2.82	2.89
$\bar{x}$	18.71		15.08		14.22	
SD	4.32		3.77		2.80	
$\bar{x}$			14.65			
SD			3.27			

A more precise correction factor could be determined through development of the gage transfer function. However, the transfer function would vary with the type of soil in which the gage was placed and the boundary conditions placed on the gage due to the backfill material. Gages that are placed in backfill materials of different degrees of compaction, causing a different amount of confinement of the gage, will produce different responses. These factors cannot be easily evaluated and each application must be individually analyzed as to how these factors affect the gage response.

Figures B-6a, b, and c present the dynamic peak pressure attenuation plots of the data presented in Table B-6. The dynamic pressure attenuation as a function of distance is approximately the same as the pressure attenuation shown in Figure B-4. However, in Figure B-6c the dynamic peak stress at the 11-foot offset is greater, due to the shallower location of the gages (18 inches instead of 21 inches for the 9- and 7-foot offset gages), and the pressure is shown to attenuate to a lower pressure level at the 9-foot offset gages. The same observation can be seen in Figure B-6b. The load cart was located at the 9-foot offset. The dynamic peak pressure indicated at the 11-foot offset is less than that indicated by the 7-foot offset gages, resulting in an asymmetric pressure distribution. This evidence tends to support the previous hypothesis that a discontinuity existed in the region of gages T-1 and T-2 near the edge of the crater repair.

Table B-2 shows the peak pressure values for the operations of the F4 aircraft. As with the load cart data a correction factor should be applied to the data to account for resonant response characteristics of the gages. The aircraft data were analyzed using the same approach as the load cart data, rise time of 10 to 90 percent of peak response to determine the frequency of the signal. The frequency for the taxi operations 1, 2, and 9 was generally proportional to the taxi speed. Operation 1 indicated 7 to 15 Hz, operation 2, 13 to 20 Hz, and operation 9, 17 to 25 Hz. However, due to the limited amount of aircraft data, scatter in the collected data, and more widely varying frequency content in the pressure signal, no definitive statement can be made concerning a correction factor on the dynamic aircraft pressure data. The one-third correction factor applied to the dynamic load cart data is a

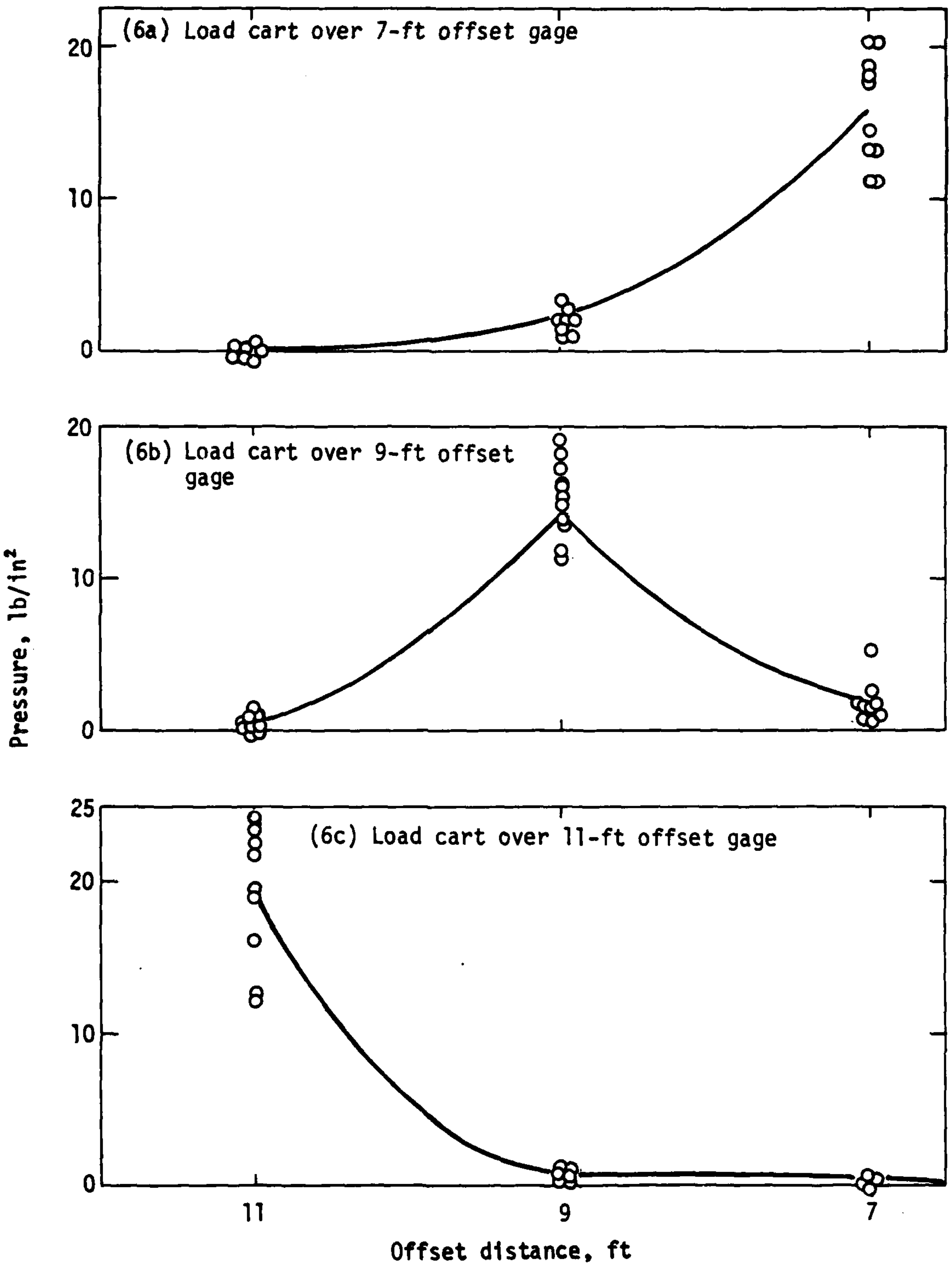


Figure B-6. Corrected F4 Load Cart Peak Pressure Attenuation.

reasonable approximation to apply to the dynamic aircraft data in lieu of no correction factor. Upon comparison of the corrected F4 aircraft data using the one-third factor with the static load cart data, the dynamic pressures are approximately 25 percent of the static stresses. The limited amount of dynamic aircraft data combined with the gage resonance characteristics prevent a correlation from being established between aircraft speed and the corresponding dynamic pressure. Under more controlled conditions and with a larger data base, this correlation may be possible. A typical data record for the F4 load cart is shown in Figure B-7.

Figure B-8 shows the static pressure distribution versus distance for the F4 load cart data and the results of a BDR code posttest calculation (dashed line). The input to the BDR code is given in Table B-7, and the elastic moduli are those determined from the in situ seismic velocity tests on the repair materials. The agreement is good.

An attempt was made to evaluate and correlate the aircraft's response, specifically the main gear compression, with the crater pressure gage response. Shown in Figure B-9 are load-time histories of the nose gear and the main gear from the North Field Interim F4 Guidance Evaluation* as the aircraft passed over the instrumented crater. The figure notes the times at which the nose gear and main gear passed over the two steel tiedown plates that were used to restrain the FOD cover. Also indicated is the time at which the main gear was in the center of the crater repair and directly above the pressure gages. On the basis of the time history, the wheel load was nominally at the aircraft static weight. The main gear compression was caused by an increased slope of the crater profile. As the main gear passed over the center of the crater, the compression decreased to approximately the static weight, due to the down slope of the profile. Thus the overregistration of the pressures cannot be explained by an increased applied load, due to the oscillation of the aircraft.

A comparison of the posttest BDR code calculation and the static field data for the C130 aircraft is shown in Figure B-10. The input to the BDR code was identical to that presented in Table B-7; it appears to provide an excellent fit to the actual code.

*Evaluation by Captain David Lenzi, December 1980.

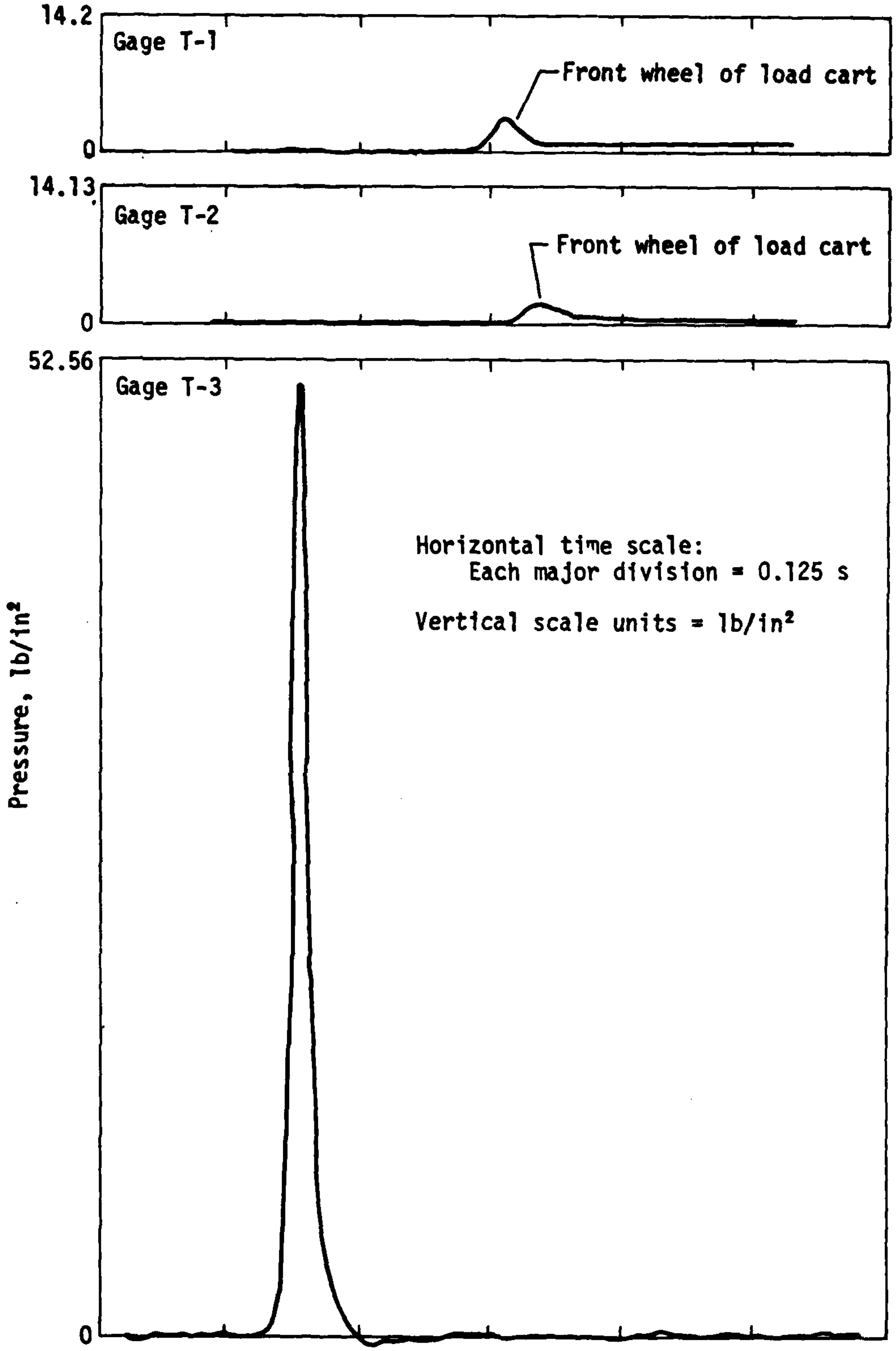


Figure B-7. Load Cart Data For Pass 34.

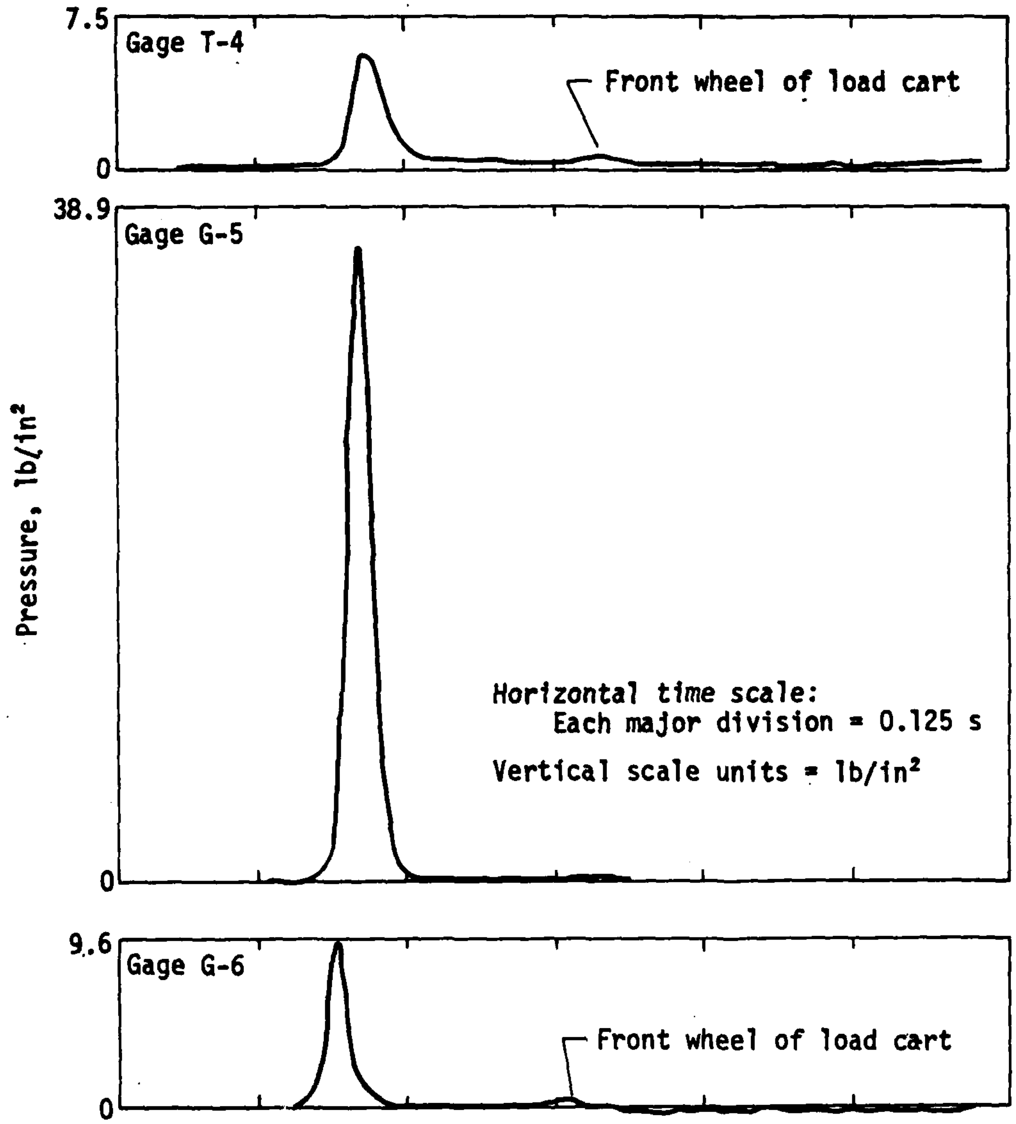


Figure B-7. Load Cart Data For Pass 34 (Concluded).

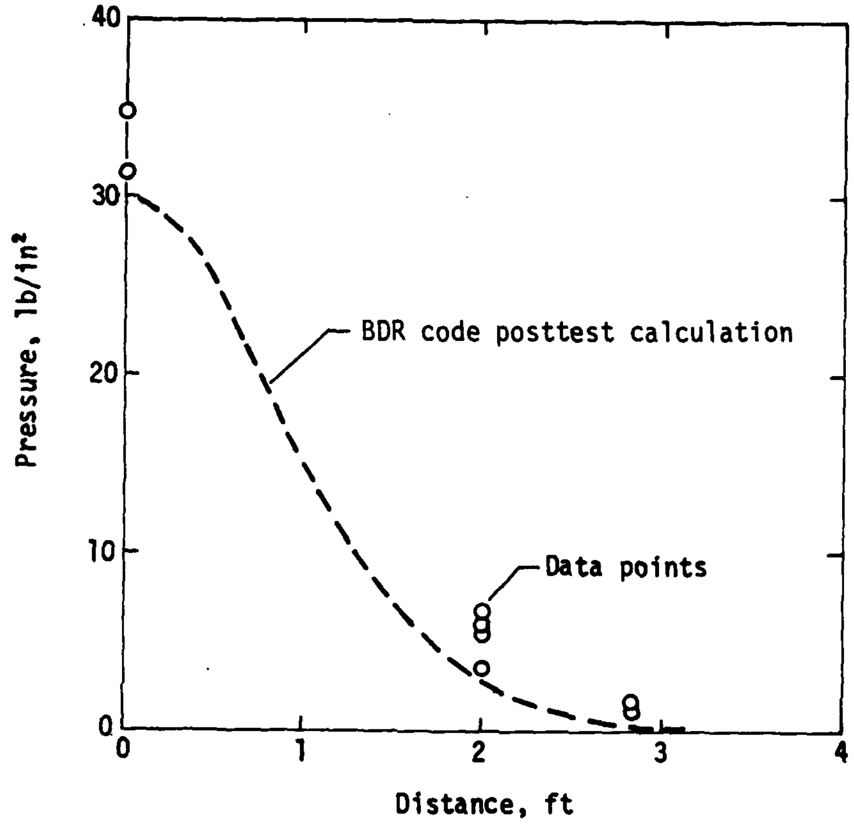


Figure B-8. Comparison Of Field And Calculated F4 Load Cart Static Pressure Attenuation At 21-Inch Depth.

TABLE B-7. BDR CODE INPUT FOR POSTTEST CALCULATION.

Material	Thickness, in	Elastic modulus, lb/in^2	Poisson's ratio	Wet unit weight, lb/in^3	Water content, percent	Plasticity index (PI)
Crushed limestone	24	62,200	0.25	145	3	4
Compacted pushback	12	77,900	0.30	120	10	4
Fallback	72	10,000	0.35	100	10	4
Native material	--	5,000	0.40	110	15	4

Table B-3 presents the peak pressure due to the C130 aircraft. The frequency content of the pressure signal was similar to the F4 aircraft signals. At slow taxi speeds the frequency was 7 to 15 Hz, showing a trend to increase proportionally with speed to 17 to 25 Hz. Operation 11 was a static load test and indicated pressures of 28 to 30 lb/in^2 beneath the load at the 21-inch depth. Most of the data from the taxi, takeoff, and landing operations indicate a lower pressure condition when compared to the static load. Again, no specific correction factor can be applied to the data due to the variability of the data. The C130 aircraft, with a centerline main gear offset of 6 feet, never passed directly above the 7-foot offset gages. Therefore, the gages never measured the peak static or dynamic pressure directly beneath the wheel. However, it is reasonable to suggest that the dynamic pressure conditions of the C130 aircraft are less than 50 percent of the static stress conditions on the basis of the results from the analyses of the F4 aircraft and load cart data.

CONCLUSIONS

The results of the seismic velocity tests on the compacted pushback and the crushed limestone indicated elastic moduli of 77,900 lb/in^2 and 62,200 lb/in^2, respectively. It appears that traffic by heavy construction equipment caused the compacted pushback to have a greater modulus than the crushed limestone. The quantity of compaction energy of the vibratory roller retained by the crushed limestone is unknown, but is estimated to be the

North Field Test

Flight No. 2 Event No. 2-2 Date 18 Aug 80

A/C configuration Heavy R/W configuration Old repairs GS 37 kt

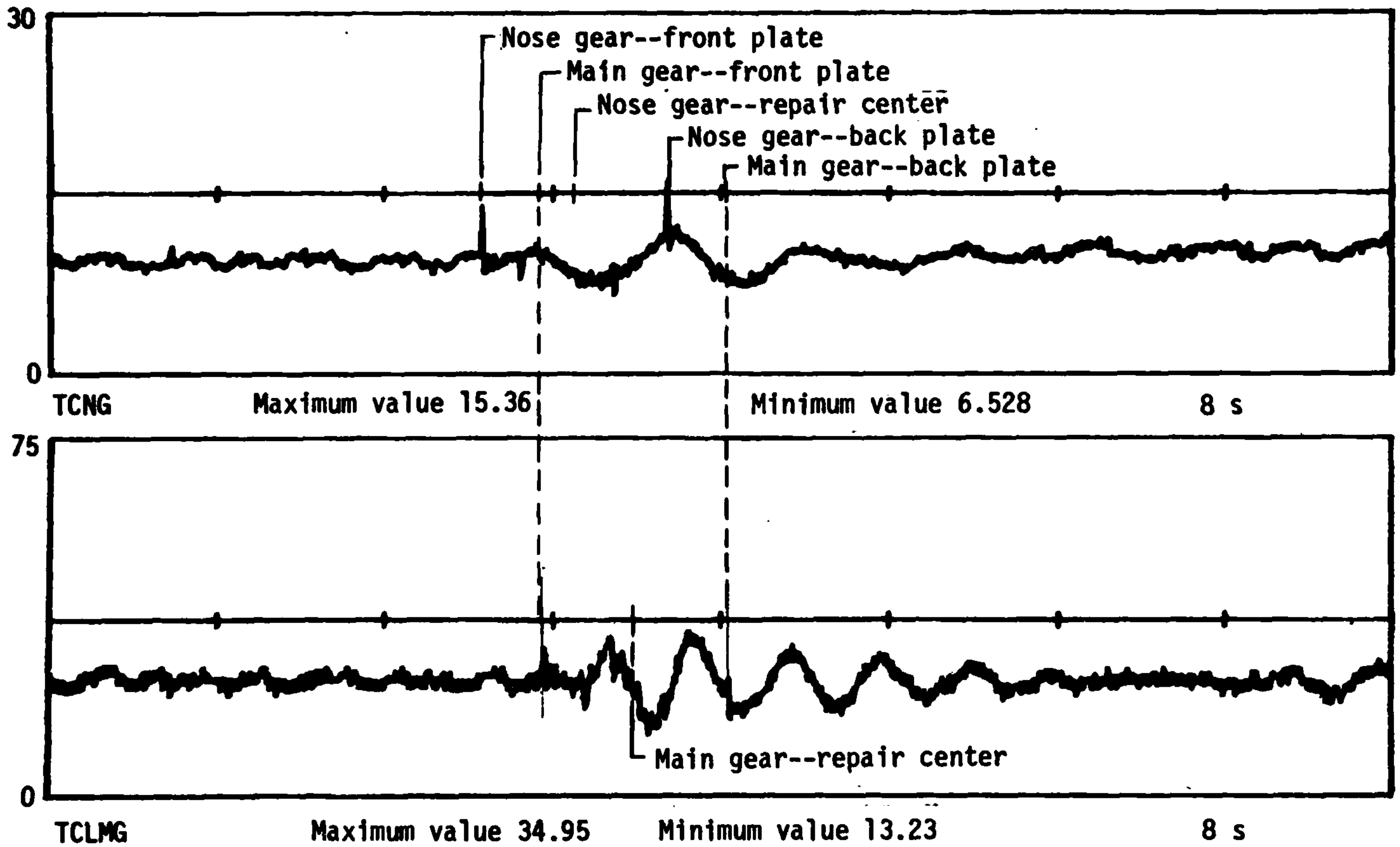


Figure B-9. F4 Aircraft Nose And Main Gear Compression Time History (After Lenzi).

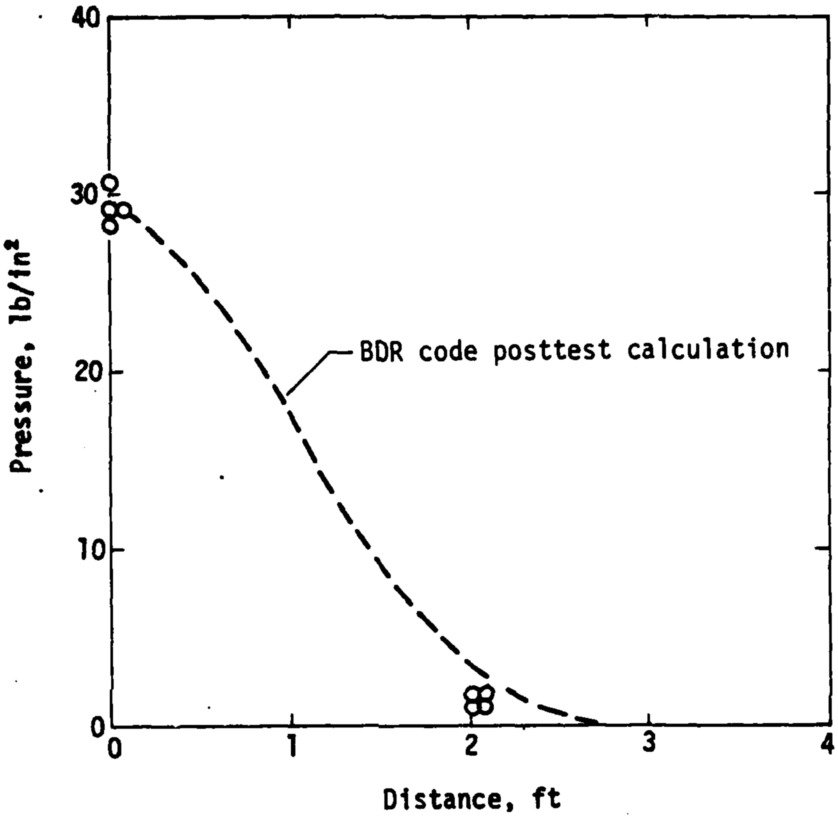


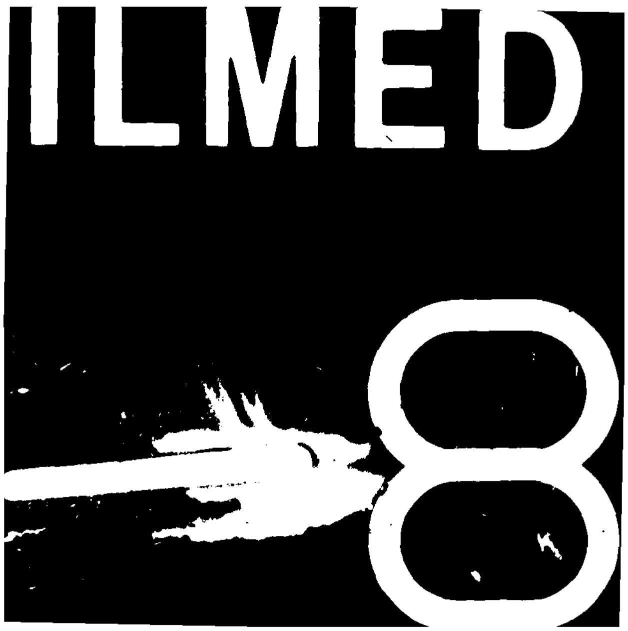
Figure B-10. Comparison Of Field And Calculated C130 Static Pressure Attenuation At 21-Inch Depth.

roller's static weight and corresponding pressure. If the energy of the roller is significantly greater, then a previously assumed crushed limestone modulus of 100,000 lb/in^2 is possible. The efficiency of the vibratory roller versus other compaction equipment should be investigated in the BDR applications. Seismic velocity measurements provide a rapid method of determining the in situ properties of the crater materials. Seismic velocity measurements could be made to determine the quality of the repair before any aircraft traffic is allowed to operate. Additional data need to be collected for a better estimate of the parameters required to evaluate the backfill materials and repaired crater performance.

Static pressures measured under the F4 load cart and C130 aircraft compared favorably with posttest BDR code calculations using the in situ elastic moduli measured by seismic velocity tests. The correlation indicates that the BDR code may be used to predict the performance of repaired craters, if the in situ properties can be accurately estimated. Elastic properties of crater backfill materials need to be studied for variability and how they are affected by repair equipment such as vibratory rollers. Additional correlations of the measured and calculated responses of repaired craters should be performed on a variety of repair materials and conditions before complete confidence is gained in the BDR code.

Due to problems with the dynamic response characteristics of the pressure gages, corrections to the dynamic load cart and aircraft traffic data were necessary. The dynamic data indicated the frequency of the pressure wave was nominally in the range of a gage resonance. On the basis of this conclusion, the dynamic data were adjusted to indicate the pressure that is believed to exist in the crater repair area due to dynamic load application by an aircraft or load cart. Dynamic pressures are approximately 10 to 50 percent of the static pressures produced by the same wheel load. For the F4 load cart at a speed of 5 to 10 knots, the dynamic pressure is nominally 25 percent of the static pressure. However, the F4 main gear compression time history indicates that, due to a nonuniform and unlevel crater surface profile, wheel loads greater than the static wheel load of the aircraft are possible. The 25 percent value is appropriate to a level crater repair and was determined after a review of the F4 instrumentation time histories. If the gages had been located closer to the front tiedown plate, greater pressures probably would have been recorded, because a greater main gear compression is indicated on the time history.

To determine more precisely the relationship between aircraft speed and the corresponding pressure produced in the crater repair, instrumentation of repairs should continue with pressure gages that have been extensively evaluated for resonant frequency characteristics and their effect on the collected data. Research should be directed at a dynamic BDR code that will allow the dynamic response of the crater repair to be predicted due to a moving aircraft wheel load. This type of a code could use as input for the applied load function the main gear compression time history from an instrumented aircraft. In this way the crater profile is not required to be known--only the response of the aircraft to the profile. An alternative input could be the aircraft responses calculated by an analytical method, such as the TAXI computer code.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